

RADIATION PROTECTION OF PATIENT DURING STEREOTACTIC RADIOSURGERY. Part I: Single isocenter phantom measurements.

Abstract

Radiation dose to organs outside the radiotherapy treatment field can be significant and clinical interest. Therefore, in order to estimate peripheral doses (PD) during the stereotactic radiosurgery treatment with Leksell Gamma Knife for single isocenter treatment technique in particular as a part of the method can be described the all plan treatment in general. Knowledge of PD can be used effectively during the optimization of treatment planning in order to deliver a very accurate dose of radiation to well-defined target with minimal damage to surrounding healthy tissue and other organs. Moreover, PD can be limiting factor during the treatment of some non-malignant lesion or pregnant woman.

Alderson-Rando phantom was used for PD measurements. The Dose of 40 Gy was delivered in a single fraction radiosurgery to midline hypothetical target volume situated close to the center of calva. Treatment planning for single target covered by 50% isodose of each collimator was performed with Leksell Gamma Plan (ver. 5.32) treatment planning system. The treatment plans for a single, 5, 10, 15, 20 and 25 shots, keeping the same position and the same doses were produced. Automatic positioning system (APS) was used for positioning of phantom during the treatment. The doses to different organs were measured during treatment by thermoluminescence dosimeter (TL).

A simple exponential function can describe dependence of measured PD on distance from target for all collimator size were utilizing. Close to the target a scattering radiation within the patient was dominant, at distances beyond 40 cm from the target this component becomes less predominated and less dependence of the collimator size. While that the PD distances beyond 40 cm was mainly due to scattered radiation in the treatment room and leakage radiation. Contributions (D_T) to the PD due the transportation of patient during the positioning were linearly increasing with the number of shots. D_T does not practically contribute to the prescribed dose in target and to the laterally scattered radiation within patient. PD depends on collimator size and this dependence is more significant close to the target where it is proportional with the C^3 and less significant far from the target where it is proportional with C only but more dependence on the number of shots.

The number of shots as well as collimator size has influence on the magnitude of PD. Reduction of number of shots can decrease the PD for sites far from the target, on other hand the influence of collimator size is more significant for organs close to the target. Weighting the effect of the collimator size and number of shots can be used effectively during the optimization procedure to choose the most suitable treatment plan.

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Commented [WU9]: "due" should be changed to "due to".

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Commented [WU11]: It is better to use "affects" instead of "has influence on".

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INTRODUCTION

Peripheral dose (PD) is the dose outside the clinically useful radiation field resulting from leakage through the collimator/source head, from scattered radiation within the patient and from surrounding materials. Knowledge of peripheral dose is essential in evaluation of radiation protection impact to patient during the treatment. However, determination of the peripheral doses (PD), such as the dose to gonads or critical organs of patients has been the subject of extensive investigation. The values were derived from measurements of contributions to the PD, i.e. from radiation scattered in the patient, leakage radiation and radiation scattered from the collimator/source. Peripheral dose can be significant for radiation sensitive organs or to implanted devices, which are situated outside the treatment volume even if it is a small fraction of target dose. The choices of treatment machine and specific peripheral dose data are quite useful in risk reduction and, perhaps, in the selection of optimal treatment technique.

Gissen, Kase and McParland [1, 2, 3, 4, 5, 6, 7 and 8] have been studying and they proposed a method for calculation of the peripheral dose to points outside the primary beam. But unfortunately this method cannot be applied to Gamma knife and linac stereotactic radiotherapy or radiosurgery. The arrangement of the arcs during stereotactic treatment has been investigated by Shepherd S. et al [9]. They found the largest dose for thyroid. They observed also that the sagittal arc increased the dose to gonads.

Majali et al [10] concluded that a simple power function could describe the relationship between the measured peripheral dose for stereotactic linac treatment and the distance from the target in case of including a sagittal arc. The dependence of measured peripheral dose on different collimator size can be described by a simple exponential function. Leakage radiation contributes very little to the dose, but becomes dominant at distances beyond 50 cm from the target. The arrangements of arcs as well as the collimator size have influence on the magnitude of peripheral dose due to contribution of exit dose and due to increasing scattering volume of target. Changing the arc arrangement and using small size collimators one can reduce the peripheral dose significantly and minimize the radiation burden to total body. In Gamma knife treatment, Novotny et al [11] concluded that an extra dose to intracranial target and extracranial sites due the patient transportation into and out of the treatment position. Cheng Yu et al [12] measured low dose to fetus in a pregnant patient treated with Gamma knife Model C.

METHODS AND MATERIALS

All experiments were carried out on Leksell Gamma Knife model C using Alderson-Rando humanoid phantom. Leksell frame was fixed to the phantom head and MRI scanning procedure used for patient was used. Treatment planning for single target covered by 50% isodose of each collimator, situated close to the center of skull, was performed with Leksell Gamma Plan (ver. 5.32) treatment planning system. The treatment plans for a single, 5, 10, 15, 20 and 25 shots, keeping the same position and the same dose to the periphery, were produced. Automatic positioning system was used for positioning of phantom during the treatment. Average dose rate at the period of experiments varied was 2.30 Gy/min.

The Alderson-Rando phantom with TLDs was placed on the treatment couch to simulate the real stereotactic treatment. Different collimator sizes (4, 8, 14, 18 mm) have been used and different number of shots was applied. The total dose delivered to the hypothetical target at maximum point was 40 Gy.

TLD Harshaw TLD 700 chips were used for measurements. Annealing of TLD has been carried out in computer controlled oven TLDO Produced by Physikalisch-Technische Werkstätten (PTW) Freiburg. The computer also controlled the HARSHAW TLD reader model 3500 (TLD-shell software). For each experimental exposure, TL dosimeters were placed on the Alderson-Rando phantom into the positions that represent the organs of interest. Those were: eyes, thyroid, breasts,

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"in evaluating the effect of radiation protection on the patient"

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"For this reason, the determination of PDs, especially the dose to the gonads or critical organs of patients, has been the subject of extensive research."

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"The selection of treatment machine and specific PD data are very useful in reducing risk".

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Commented [WU24]: It is better to use "affect" instead of "have influence on".

Commented [WU25]: "contribution" should be changed to "the contribution".

Commented [WU26]: This phrase should be changed to "small collimator sizes".

Commented [WU27]: Because this study is an experimental study, it would be helpful to include a image of the gamma knife machine and phantom used in this research. Also, specifying the different components of the Gamma Knife machine, mentioned in this manuscript, can be instructive.

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Commented [WU29]: This sentence should be changed to "MRI scanning procedure was used for the patient".

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abdomen (umbilicus) and ovaries. A new interesting measuring point, compared to previous experiments [11]; was introduced on the top of the skull, because this point is during co-ordinate repositioning permanently exposed by scattered and leakage radiation from the unit. The accident, which happened [14] quite clearly shows the importance of dose knowledge at this point. Three TLD chips encapsulated in polyethylene capsules, ensuring full build-up, were placed on each location. Total uncertainty of the TLD measurement was estimated to be around $\pm 5\% 1\sigma$.

RESULTS AND DISCUSSION

Measurements of PD are shown in figure (1-a, b, c, d) for different collimator sizes and a different number of shots. Dependence of measured PD on the distance from target can be described by exponential function. The data can be fitted to an equation:

$$D_{PD,C,n} = \alpha e^{-\beta d} \quad (1)$$

Where α and β are the fitting parameters, d the distance from the center of target. Subscript C means collimator size. $D_{PD,C,n}$ is the normalized dose to the 50% of the maxim target dose. The coefficient of correlation for equation (1) varied between (± 0.98 and ± 0.99). As it was expected the organs located in the nearest vicinity of the target receive higher doses depending on the size of collimator because the scatter radiation from the target volume is the principal dose contributor to those organs. At distances beyond 40 cm from the target the dose due the scattered radiation from the unit and room and the leakage radiation was predominant and the influence of collimator size is becoming no more significant.

Figure 2 (a, b, c, d) illustrates the dependence of the PD for each collimator size on the applied number of shots. From the figure 2 one can see the linear relationship between the PD and the number of shots. The data can be fitted for all different measured points to equation:

$$D_{PD,C,n} = a + bn \quad (2)$$

Where, a and b are the fitting parameters, n the number of shots. The coefficient of correlation for equation (2) varied between (± 0.80 and ± 0.99). The increasing value of PD with the number of shots is related to the increasing influence of scattered and leakage radiation from the unit during the positioning of the patient when the couch is moved outside the radiation focus, but not fully out. Coefficient a represents the PD which is obtained when no shots is applied, i.e. scatter dose from a target volume. Coefficient b is an increment due to dose obtained during positioning of patient into treatment position. We can call necessary time for positioning as transit time and the dose, which is obtained during this time as "transit" dose. This transit dose depends on transit time, i.e. the time necessary for repositioning of all shots and on a dose rate of the LGK. Since the movement of patient's head from one position to another using APS system is limited by maximal movement in X-axis 20 mm, Y-axis 20 mm, Z-axis 40 mm, it is possible to estimate an average time necessary for transit. Experimentally was estimated that average is about 30s (range 20-90s). It is necessary to emphasize that there is difference in transit time between Leksell gamma Knife model C with automatic positioning system (APS) and the original model B [11] or U, where the couch was completely removed during the manual repositioning of shots.

To find the general relation between PD and target dose for any organ of interests one has to make a few propositions. According to Giessen [6] the dose to any point Q outside the useful beam from the radiation scattered at target (point P) is proportional to:

$$D_{Psc}(Q) = \phi_{Psc}(Q) \times E_{sc} \times \mu_{en} \quad (3)$$

Where $D_{Psc}(Q)$ is the dose at Q due the scattered radiation at P; ϕ_{Psc} is the fluence at point Q, E_{sc} and μ_{en} are the energy of the scattered photons and mass energy absorption coefficient, respectively.

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Commented [WU38]: A comma should be used after "the target".

Commented [WU39]: "due" should be changed to "due to".

Commented [WU40]: From figure 1-a, for collimator size=4mm, the value of PD for distances greater than 40 cm is not a constant value. Therefore, this result seems to be true for collimator sizes larger than 4 mm.

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Commented [WU44]: This sentence should be changed as "Experimentally, it was estimated that the average transit time is about 30s (range 20-90s)."

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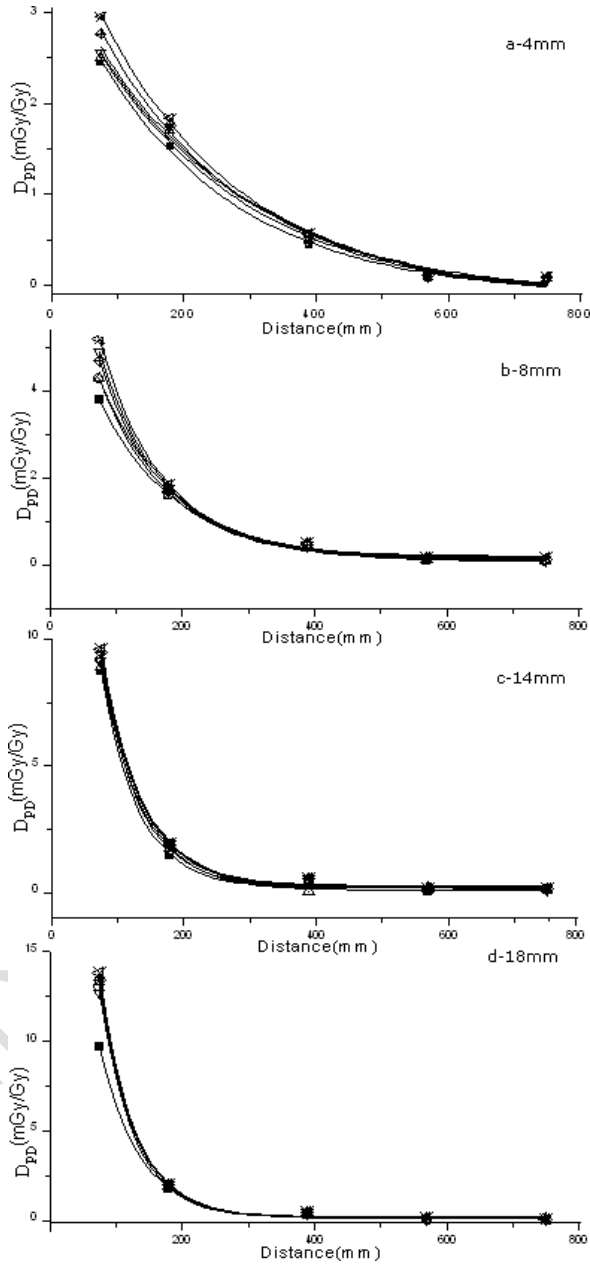


Fig. 1: D_{PD} as function of collimator size (\boxtimes $n=1$, \boxminus $n=5$, \boxplus $n=10$, \boxtimes $n=15$, \boxminus $n=20$, \boxplus $n=25$).

This means that the photon fluence ϕ_{psc} at point Q is proportional to that at point P or to the target dose D_{target} . The total peripheral dose is the sum of the scatter dose from patient's target ($D_{sc,target}$), leakage and scattered dose ($D_{sc,leakage}$) from the source in the head of the treatment unit. The

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contributions of radiation scattered from the floor, walls, or ceiling are negligible [1]. One can thus for any measured point Q write:

$$PD_{total}(Q) = D_{sc,target}(Q) + D_{sc,leakage}(Q) \quad (4)$$

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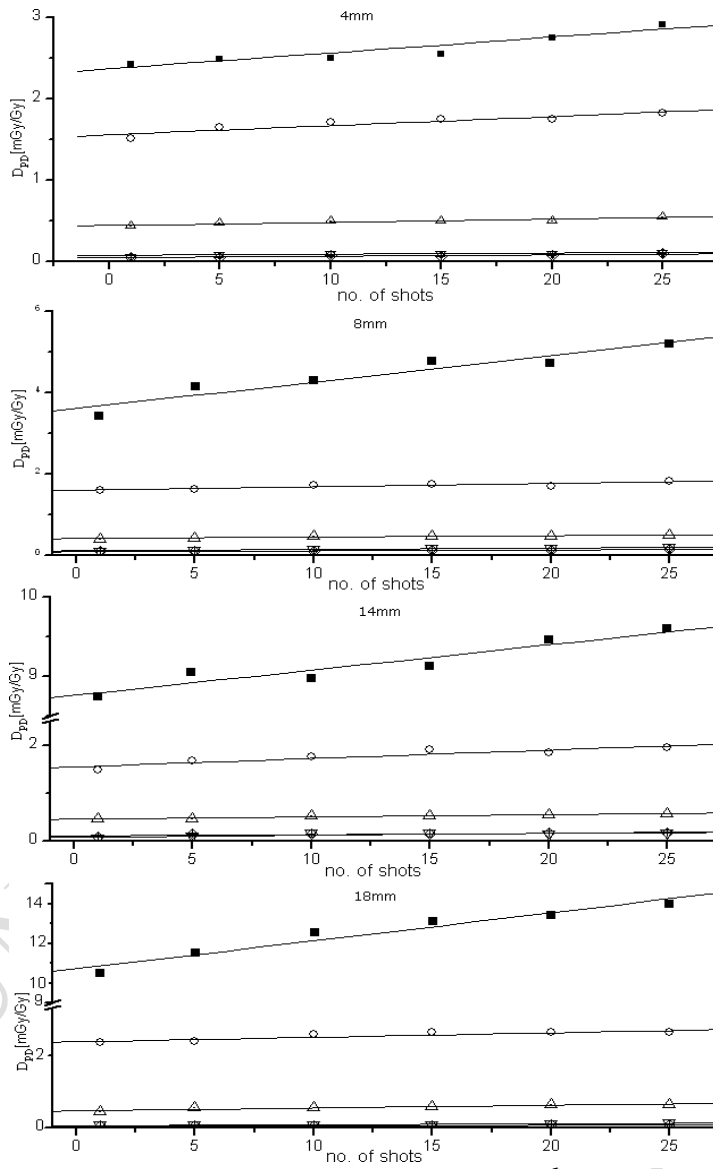


Fig. 2: D_{PD} as function of number of shots (Eyes, Thyroid, Breasts, abdomen, Ovary).

According equation (4), equation (2) included two terms is represented the two component of radiation which are contributed to the total peripheral dose. The factor a is represented the scattered radiation within the patient while the last term is represented the radiation of the scattered and leakage radiation from the treatment unit. And this can be indicated by figure (3) that shown the dependence of the factor a as function distance. Moreover, the values of factor a , which are obtained by extrapolated when $n=0$ can be fitted closely to an exponential relationship as shown in equation (5) as:

$$a = a_0 e^{-\beta d} \quad (5)$$

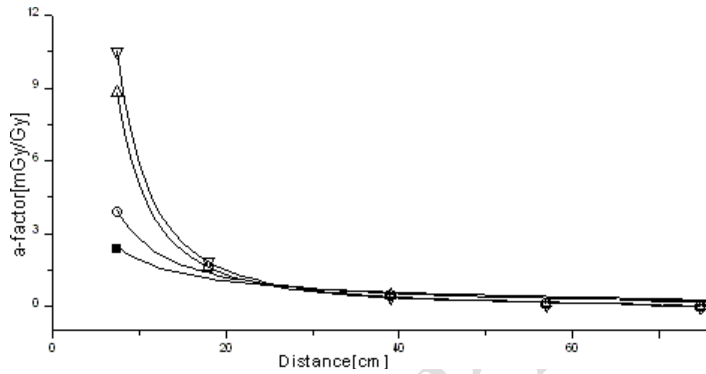


Fig. 3: the factor a as function of distance (⊠ 4mm, ⊡ 8mm, ⊙ 14mm, ⊠ 18mm).

At distance $d=0$, the values of factor a_0 can be fitted perfectly as liner function of C^3 as shown in figure (4), and the fitting equation was:

$$a_0 = 1.35C^3 + 4.25 \quad (6)$$

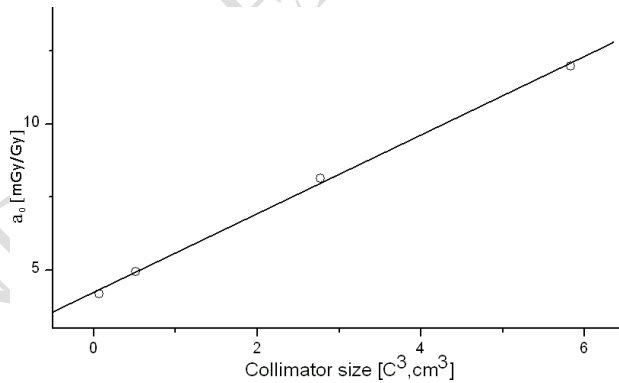


Fig. 4: the value of factor (a_0) as function of the [Collimator size, C^3].

The values of the factor b can be also fatted closely as inverse power function with the distance as shown in figure (5) and the fitting equation was:

$$b = \frac{k(C)}{d^{q(C)}} \quad (6)$$

Where, $k(C)$ and $q(C)$ are the fitting factors. Both of them depend on the collimator size as shown in figure (6).

As a result equation (2) can be rewriting as:

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"Therefore, the first term (a) in equation (2) represents the scattered radiation within the patient and the second term (bn) represents the scattered and leakage radiations from the treatment unit."

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Commented [WU55]: "liner" should be changed to "linear".

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$$D = 1.35C^3e^{-\beta d} + 4.25e^{-\beta d} + [k(C) / d^{q(C)}]n \quad (7)$$

The values of factor k can be fitted closely to an exponential relationship with collimator size as:

$$k(C) = 0.11e^{2.3C} \quad (8)$$

While the factor q can be also fitted closely to a linear relationship with collimator size and the fitting equation was:

$$q(C) = 0.65C + 0.9 \quad (9)$$

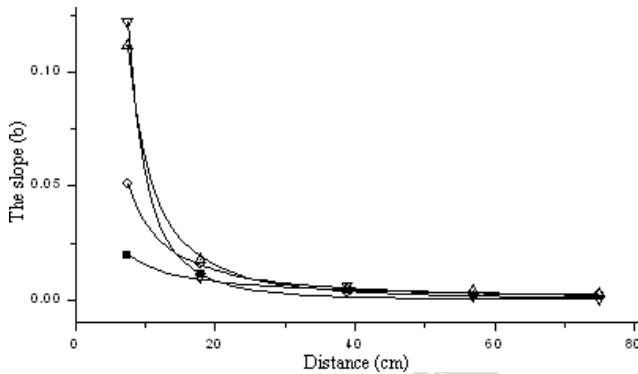


Fig. 5: the factor b as function of the distance (⊠ 4mm, ⊞ 8mm, ⊙ 14mm, ⊠ 18mm).

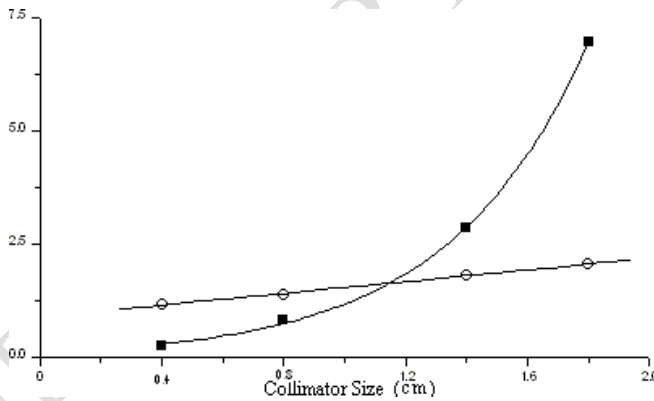


Fig. 5: the factor k and q as function of the collimator size, C (⊠ k , ⊙ q).

Equation (7), (8) and (9) indicated that the peripheral dose as dependence of the collimator size at the sites close to target has proportional with the C^3 where the scattered radiation is more significant. Meanwhile, the peripheral dose at the sites far from the target has been proportional with C where the other component was more significant.

Regarding to the coefficient β , Kase et al [6] mentioned that this factor might be represents the attenuation coefficient of scattered photons in water, while McParland [8] mentioned explicitly that is the attenuation coefficient. However, based on the data obtained by this experiment we found the average value of this coefficient was $(0.00685 \pm 0.001) \text{ mm}^{-1}$. Where the linear attenuation coefficient used by the treatment planning system is 0.0063 mm^{-1} based on the tissue equivalent material and photon energy of 1.25 MeV photons of ^{60}Co disintegration. The value of coefficient β correspond to

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the photon energy < 1.25 MeV which is the energy of scattered photons on the most forward direction depending of the geometry of the treatment.

Conclusion

The number of shots as well as collimator size has influence on the magnitude of PD. Reduction of number of shots can decrease the PD for sites far from the target with minim or negligible effect on the prescribed dose. Therefore, reducing the risk when the subject of protection is pregnant women if the treatment is unavoidable or patient in the productive age, on other hand the influence of collimator size is more significant for organs close to the target. Weighting the effect of the collimator size and number of shots can be used effectively during the optimization procedure to choose the most suitable treatment plan.

References

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19. Khan F. M., *The physics of radiation therapy.* Williams & Wilkins, (1994).

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20. Diallo I. et al., Estimation of the radiation dose delivered to any point outside the target volume per patient treated with external beam radiotherapy. *Radiotherapy and Oncology*. (38): 269-271(1996).
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