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DEPENDENCE OF DOSIMETRIC PARAMETERS IN STEREOTACTIC RADIOSURGERY OF SOLITARY BRAIN METASTASIS ON USING NORMAL TISSUE OBJECTIVE FUNCTION VARIATIONS

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ABSTRACT

Technical approaches to maximize therapeutic ratio by achieving local control of disease and/or sparing normal tissue are of interest. One approach is to test photon field size reduction in the treatment of single brain metastasis. This study quantifies effects of field size (FS) reduction in terms of dosimetric parameters i.e., gradient index (GI) and 40%-isodose volume (40%-IDV). Initial testing was done on a virtual water equivalent homogeneous cylindrical phantom and the experiment was furthered by creating irradiation plans on fourteen previously treated subjects having single brain metastasis. Field size was reduced using a normal tissue objective (NTO) exponential function by increasing dose fall-off. Three fall-off values 0.2, 0.6, and 1.0 with end dose=10% of prescribed dose, and priority=100 of NTO function combinations were employed and named as A, B, and C respectively. Combination C was chosen as baseline, due to steep fall-off exhibited, for comparison. In case of virtual phantom irradiation, FS reduced gradually on application of NTO functions A through C. For real subjects, FS due to three NTO combinations was 12.1±2.5 cm^2, 10.3±1.6 cm^2, and 9.6±1.7 cm^2. GI decreased drastically and was 6.83±2.67, 4.98±2.04, and 4.50±1.45. Similarly, 40%-IDV was 20.38±7.74 cm^3, 15.87±7.61 cm^3, and 15.04±7.88 cm^3. Combination C exhibited statistically significant reduction in FS as compared to A and B, $P < 0.01$. For GI and 40%-IDV, considerable reductions in favour of combination C were observed in comparison to A, $P<0.0001$. Preliminary results indicate limiting FS using NTO function reduces GI and 40%-IDV for better normal tissue sparing.

Keywords: - field size, gradient index, brain metastasis.

INTRODUCTION

The primary aim of radiation therapy is to maximize tumoricidal dose and to minimize normal tissue damage. Usually photon fields are used for the irradiation of target regions. This also causes normal tissue exposure. Treatment planning techniques to reduce normal tissue exposure are of interest. Exposure decreases outside the photon field extents, which means that field collimation may be limited to achieve aims of planning.

One approach to reduce normal tissue exposure is to constrain the field collimation with the help of a mathematical function fed to the treatment planning software [1]. Few studies have evaluated the effects of modeling normal tissue dose gradients with the help of such mathematical functions [2-4]. In this study we report the effects of the photon field reduction on the dosimetric parameters for radiosurgical treatment of single brain targets. Previous studies reported the effects of using a mathematical function but did not report as to why the dose gradient occurs [5]. Here we report the metrics such as field size (FS), gradient index (GI) and dose spillage in terms of 40% isodose volume (40%-IDV) around the target. This preliminary work is initially carried out on a virtual cylindrical phantom and then extended to realistic cases. The systematic analysis first records the effects of using normal tissue gradient function on phantom in terms of field size and dose spillage changes. In the later stage, for realistic cases gradient measure is recorded additionally.

MATERIALS AND METHODS

A normal tissue gradient function can be expressed as an exponentially decreasing function in terms of distance from the target periphery, slope of dose gradient from an initial dose at target periphery and a final dose at a far radial distance. These variables may be manipulated to change the steepness of the function.

The function is expressed as

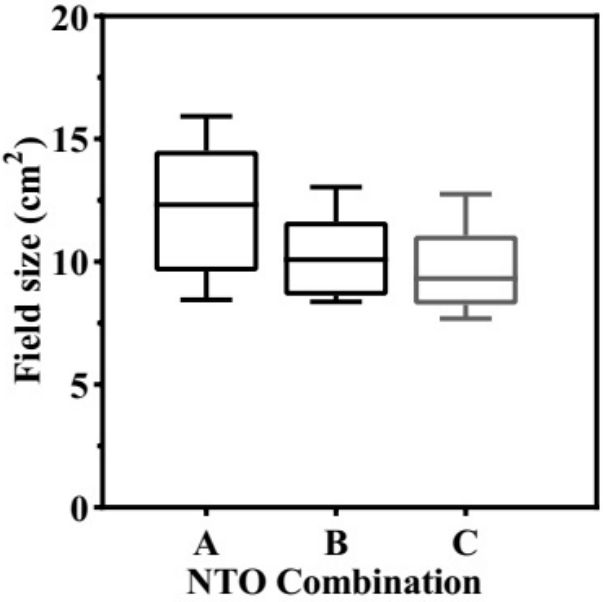
$$f(x) = f_0\, e^{-k(x-x_{start})} + f_\infty\,(1- e^{-k(x-x_{start})}),\ \text{when } x >= x_{start}$$

$$f_0,\ \text{when } x < x_{start}$$

where x_{start} = distance from target border, f_0 = start dose, f_∞= far end dose, k = fall-off.

A virtual phantom was created having 15 cm diameter and 20 cm height and a sphere of 1 cm diameter located at phantom center was the target. The target dose-volume objectives include minimum and maximum target doses. A minimum prescribed dose of 10 Gy and a maximum of 13 Gy formed the dose-volume objective set. A priority equal to 100 was assigned to these objectives. To obtain varied degrees of gradient the fall-off (k) parameter was assigned three values 0.2, 0.6, and 1.0. The other parameters were fixed as x_{start} = 1 mm, f_0 = 95% of prescribed target dose, f_∞= 10 of prescribed target dose. The priority of NTO was set as 100, which equals that of dose-volume objective. Thus, three combinations were formed combining the three fall-off values with other parameters. These were name as A, B, and C. The combination C was the baseline group for comparison with other combination groups.

Thirteen non-coplanar 6 MV static photon beams were equally spaced around the target in the phantom. Each beam collimated the target with a high definition multi leaf collimator. The intensity modulated technique was used for achieving target dose-volume objectives. Observations of field size were recorded on the application of the three normal tissue gradient function parameter combinations. Further the experiment was conducted on fourteen cases on single brain metastasis treated previously. These cases were planned by placing non-coplanar static photon beams. The normal tissue gradient function combinations and dose-volume objectives were the same as used for the phantom case, but renormalized to a prescription dose of 20 Gy [6]. After the dose is optimized to the target, final dose was computed. Final dose computation was carried out by using an anisotropic analytical algorithm. The results of FS, GI, and 40%-IDV were recorded. In the present study FS is taken as the maximum extents of the collimator jaws. GI is defined as the ratio of half prescription dose-volume to the prescription dose-volume [7]. The 40%-IDV represents 40% of prescription dose-volume [8]. Data of all these metrics was summarized in terms of mean and standard deviation. The differences between metrics was analysed for statistical significance using one way analysis of variance test.

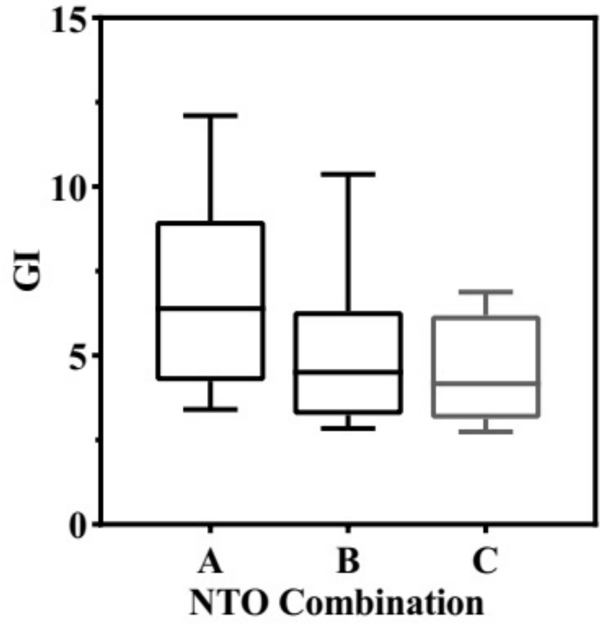


RESULTS AND DISCUSSION

In case of virtual phantom irradiation, FS reduced gradually from 6.72 cm^2 to 5.87 cm^2 on application of NTO functions A through C. The percentage difference between FS for combinations A and C is 12.6%. Following the trend shown for the phantom case, the FS also reduced for the solitary brain metastasis cases. With increase in NTO fall-off from $k = 0.2$ (A) to 1.0 (C), the FS reduced from 12.1 ± 2.5 cm^2 to 9.6 ± 1.7 cm^2 ($P < 0.0001$ for A vs. C). Figure 1 shows the trend of FS versus the NTO function variations for the fourteen cases.

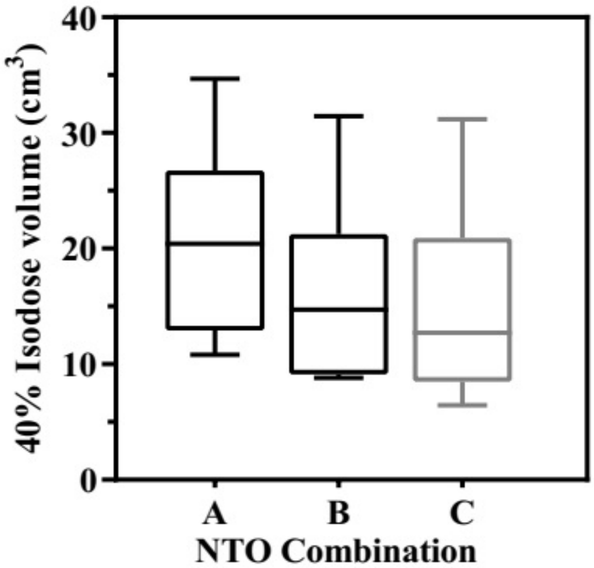
Figure 1. FS versus NTO function parameter variation for all cases.

The optimizer algorithm generates field sizes according to the NTO parameters, in particular with regard to the fall-off (k). In this study only the fall-off parameter is varied and other parameters are kept unaltered. The field size becomes constrained with the use of fall-off values that specify steeper slope of NTO function curve. Previous studies examined variations of fall-off and priority parameters [2]. Accordingly as the FS reduces with steep fall-off of NTO curve, the points in normal tissue far from the target receive lesser doses. Thus, for the brain metastasis cases the least GI was found for NTO combination C, which has the steepest fall-off of



1.0 cm^{-1}. The box plot of GI versus the NTO variations shows a monotonically decreasing trend. The GI values for the three NTO combinations A, B, and C are 6.83±2.67, 4.98±2.04, and 4.49±1.45 respectively, ($P < 0.0001$ for A vs. C).

Figure 2. GI versus NTO function parameter



variation for all cases.

Figure 3. 40%-IDV versus NTO function parameter variation for all cases

Similarly, the 40%-IDV was found to be least for the steepest fall-off value (k=1 cm^{-1}) of the NTO function. The pattern of 40%-IDV for each NTO combination is depicted in figure 3 for all the cases. The mean and standard deviation values of 40%-IDV corresponding to the NTO functions examined, consecutively are 20.38±7.74 cm^3, 15.87±7.61 cm^3, and 15.04±7.88 cm^3 ($P < 0.0001$ for A vs. C). This result is due to the limitation of field size imposed by fall-off of the NTO function curve [2,3,5]. The overall results of this study aligns with a prior investigation which suggested that adjustment of beam margins leads to better gradient in normal tissue with associated target dose heterogeneity [9].

CONCLUSIONS

This study systematically examines photon field reduction using Normal tissue objective function (NTO) for virtual and real cases for 6 MV X-ray beams. As NTO fall-off increases from 0.2 mm^{-1} to 1.0 mm^{-1} field size reduces gradually. Preliminary results indicate that limiting FS using NTO function reduces GI and 40%-IDV significantly, for better normal tissue sparing. Photon field reduction leads to dose gradient in normal tissue thereby reducing lethal dose to normal brain.

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