Improvement of the penumbra for small radiosurgical fields using flattening filter free low megavoltage beams

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Abstract

Background: *In stereotactic radiosurgery, sharp beam edges have clear advantages to spare normal tissues. In general, the dose gradient is a limiting factor in minimizing dose to nearby critical structures for clinical cases. Therefore the penumbral width should be diminished.*

Methods: *A Varian Clinac 2100 linear accelerator equipped with in-house designed radiosurgical collimator was modeled using the EGSnrc/BEAMnrc Monte Carlo code and compared with the measurements. The 0.015 cm^3 PinPoint chamber was used to measure the 6 MV photon beam characteristics and to validate Monte Carlo calculations. Additional to the standard (STD) linac, a flattening filter free (FFF) linac was simulated. Percent depth doses, beam profiles and output factors were calculated for small field sizes with diameter of 5, 10, 20 and 30 mm with DOSXYZnrc. The mean energy and photon fluence at the water surface were calculated with BEAMDP for both FFF linac and STD linacs.*

Results: *The penumbra width (80%-20%) was decreased by 0.5, 0.3, 0.2 and 0.2 mm for field sizes of 5, 10, 20 and 30 mm respectively when removing the FF. The fluence of photons at the surface increased up to 3.6 times and the mean energy decreased by a factor of 0.69 when removing the FF. The penumbra width (80%-20%) decreased by 17% when a 2 MeV monoenergetic electron pencil beam incident on the target is used instead of 6.2 MeV.*

Verbesserung des Halbschattens eines kleinen Photonenfeldes durch einen ausgleichsfilterlosen Strahl niedriger Energie

Zusammenfassung

Hintergrund: *In der Radiochirurgie sind scharfe Feldgrenzen notwendig, um Normalgewebe zu schonen. Im Allgemeinen begrenzt der endliche Dosisgradient die Möglichkeit benachbarte kritische Strukturen zu schonen. Deshalb sollte die Halbschattenbreite verringert werden.*

Methoden: *Ein Varian-Clinac-2100-Linearbeschleuniger, ausgerüstet mit Rundkollimatoren wurde mit Hilfe des EGSnrc/BEAMnrc-Monte-Carlo-Codes modelliert und die ermittelten Dosiswerte mit Messungen verglichen. Eine 0,015cm^3-PinPoint-Kammer wurde zur Messung der Feldcharakteristika verwendet, mit denen die Monte-Carlo-Rechnungen validiert wurden. Zusätzlich zum Standard-Linac (STD) wurde ein ausgleichsfilterloser Linac (FFF) simuliert. Es wurden Tiefendosisverläufe, Querprofile und Streufaktoren für die Felddurchmesser 5, 10, 20 und 30 mm mit DOSXYZnrc berechnet. Die mittlere Energie und die Photonenfluenz an der Wasseroberfläche wurden für beide Fälle, STD und FFF mittels BEAMDP berechnet und verglichen.*

Ergebnisse: *Die Halbschattenbreite (80%-20%) minderte sich um 0,5, 0,3, 0,2 und 0,2 mm für Felddurchmesser*

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Conclusions: *It was found that the penumbra of small field sizes is decreased by removing the FF. Likewise using low megavoltage photons reduced the beam penumbra maintaining adequate penetration and skin sparing.*

Keywords: Small field, penumbra, flattening filter, Monte Carlo

von 5, 10, 20 bzw. 30 mm, wenn man den Ausgleichsfilter entfernte. Die Photonenfluenz erhöhte sich auf das bis zu 3,6-fache, wobei die mittlere Energie um den Faktor 0,69 vermindert wurde. Die Halbschattenbreite verringerte sich um weitere 17%, wenn die Grenzenergie von 6,2MeV auf 2MeV reduziert wurde.

Schlussfolgerung: *Wir stellten fest, dass der Halbschatten reduziert wurde wenn der Ausgleichsfilter entfernt wurde. Auch eine Verringerung der Beschleunigungsspannung minderte den Halbschatten, wobei Durchdringung und Oberflächendosis des Photonenstrahls in einem brauchbaren Bereich blieben.*

Schlüsselwörter: kleine Felder, Halbschatten, Ausgleichsfilter, Monte Carlo

Background

Stereotactic radiosurgery (SRS) is a special radiotherapy technique that treats well defined and small volume brain lesions with many focused beams and precise delivery of high prescribed doses of ionizing radiation while minimizing dose to nearby normal tissues [1,2]. The main characteristics of SRS are: i) the relatively small volume of the target tissue, ii) radiation is delivered over a very small number of fractions, iii) the dose per fraction is large [3]. Radiosurgical field sizes are typically smaller than 4 cm in diameter and the critical structures are in proximity of the targets. Hence, high accuracy in treatment planning and dose delivery is recommended. The aim in radiosurgery is to deliver dose to the target with a positional accuracy of ±1 mm and accuracy of ±5% in dose delivery with steep dose falloff outside the target volume [4].

Sharp beam edges have clear advantages for normal tissue prevention because they require a smaller beam aperture margin [5]. In general, the dose gradient is a limiting factor in minimizing dose to nearby critical structures for clinical cases [6,7].

Therefore the penumbral width should be diminished to achieve a steep dose gradient. The penumbra of a radiosurgical X-ray beam is mainly the result of two factors: the geometric and the radiological. The geometric penumbra is created by the finite sized X-ray source and its occlusion by the collimator assembly.

The radiological penumbra is the result of scattered photons and secondary electrons generated in tissue. It increases with increasing beam energy and decreasing tissue density. It has been shown that for field sizes less than $4\times4\,cm^2$, the secondary electron range is the primary contributor to radiological penumbra [8–10]. Therefore the radiological penumbra can be reduced by decreasing the photon energy for small fields. Keller et al have reported that intermediate energy photons in the energy range of 800 kVp (with effective photon energy between 200 and 400 keV) are optimal for a small penumbra, while still providing sufficient penetration and skin sparing when multiple beams are used [10–12].

Several papers on dosimetric characteristics of unflattened photon beams have been published [13–18]. The purpose of this work was to model the Varian Clinac 2100 linac equipped with circular collimators by means of the EGSnrc/BEAMnrc Monte-Carlo code. The benefits of the flattening filter free (FFF) linac over the standard (STD) linac for small fields were investigated, the effects of using lower energy photons on PDD, profile and especially radiological penumbra at various small field sizes was evaluated using MC simulation. Field sizes down to 5 mm diameter were studied.

Materials and Methods

Measurements

The output factor, profiles and central axis depth doses were measured for different circular fields (diameters: 5, 10, 20 and 30 mm), in a water tank ($50\times50\times70\,cm^3$) (PTW, Freiburg, Germany). All measurements were performed at source to surface distance (SSD) of 100 cm and at 5 cm depth in water. The 6MV photon beam, corresponding to $TPR_{20,10}(10)$ of 0.667 was investigated.

The linac was equipped with an in-house designed radiosurgical collimator consisting of collimator housing and divergent cylindrical treatment cones that produce fields of 5, 10, 20 and 30 mm diameter at the isocentre. The cones were made of Lead surrounded by Aluminum. Circular fields were created with the linac's jaws set to side length of 5 cm and 3 cm at isocentre for 30 mm diameter and smaller cones, respectively.

The dosimetry system used was a PinPoint chamber and a PTW UNIDOS® Universal electrometer. The PinPoint chamber (PTW-Freiburg, Germany, type 31006) is a waterproof $0.015\,cm^3$ cylindrical air chamber with a central electrode