Modification of the 4 MeV electron beam from a linear accelerator for irradiation of small superficial skin tumors

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ABSTRACT
Uniform dose distribution with steep lateral gradient within depth range of 0–0.5 cm is crucial to be able to treat small skin lesions. The standard nominal 4 MeV electron beam from Elekta Versa HD linear accelerator was modified with degrading filter to remove the lateral scatter from treatment head and minimize the penumbra. The energy degrading method was verified based on dosimetric properties and output factors (OFs) with comparison of four types of measurement methods. The properties of degraded 4 MeV electron beam and developed electron applicators seem optimal for treating small targets near the skin surface.

1. Introduction
Small superficial non-melanotic skin tumors were traditionally among the first curative indications of radiation therapy (RT). As the incidence of basal cell and spinocellular carcinoma is rapidly increasing in the Western countries [1], RT is still widely used even though the awareness of long-term consequences has increased. Especially in the facial area where the surgical procedures are challenging, and among the elderly people, RT has its place [2].

The most optimal radiation modality for treating superficial tumors with less than 0.5 cm invasion depth, would produce uniform dose distribution, easy protection of adjacent healthy structures, narrow penumbra, insensitivity to moderate density variations or complex surface geometry, and fast dose fall-off for areas deeper than 0.5 cm. The potential techniques include: X-ray contact therapy devices with tube voltage ≤50 kV, orthovoltage devices with tube voltage ≥150 kV, electron beams from the linear accelerators, superficial brachytherapy applicators with Ir-192 afterloaders, and radioactive superficial molds, like Re-188 paste [3–5]. None of the existing techniques includes all the optimal treatment features.

The degraded beam contains scattered electrons from the filter, which results wider energy spectrum and energy distribution of electrons at the skin surface. To be able to reach acceptable field homogeneity the beam output must be compromised [7,8].

The aim of this work was to develop a method to produce uniform dose distribution within the depth range 0–0.5 cm and as fast dose fall-off as possible in deeper areas. Our approach was to utilize the standard nominal 4 MeV electron beam from the linear accelerator with the beam degrading filter to reduce the energy of about 1.2 MeV. The lateral uniformity was controlled with the extra collimation brought close to the skin surface. After developed an applicator type that fulfilled basic requirements the dose distribution data was collected for treatment planning and patient safety aspects. Comparative absolute dose measurements were performed using four independent methods.

2. Material and methods

2.1. Design of the applicator

The modifications were designed to fit into the structure of the standard square 6 × 6 cm² electron applicator from the Elekta Versa HD (Elekta AB, Stockholm, Sweden) linear accelerator with minimal changes and increase of weight. The lowest electron energy ($E_{\text{opt}} = 1.7$ cm for the $20 \times 20$ cm² field size, nominal energy 4 MeV) was degraded with a 0.6 cm thick Plexiglas (polymethyl methacrylate, PMMA) plate located in the second aperture plate. To restrict lateral electron scatter from the plate, an additional 5 cm long PMMA...
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D S
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\[ D_{\text{deg}} = \left( \frac{S_{\text{deg}}^{\text{ref}} k_{\text{pol,deg}} k_{\text{deg}} m_{\text{deg}} D_{\text{ref}}}{S_{\text{deg}}^{\text{ref}} k_{\text{pol,ref}} k_{\text{ref}} m_{\text{ref}} D_{\text{ref}}} \right) \]

(1)

These results were compared to Sun Nuclear electron diode measurements and Gafchromic® EB3 film irradiations at same depths to 4 Gy dose which was calculated from IC measurements (Eq. (1)). The diode measurement was done in water and the films were irradiated in CIRS plastic water at \( d_{\text{max}} \) of corresponding beams. No corrections for diode or film readings were applied, except normalization to reference dose with the non-degraded 4 MeV beam. For the absolute OF definition, the OFs from the IC, diode and Gafchromic® film measurements were analyzed with \( 10 \times 10 \text{cm}^2 \) 4 MeV electron field as a reference, because the field was possible to measure with both ICs PTW Roos and 23342, and this made it possible to set the field OF to value 1.

As a totally independent set of measurements irradiations using optically stimulated luminescence dosimeters (OSLDs) from IROC (Imaging and Radiation Oncology Core at MD Anderson Cancer Center, Houston, TX, USA) were performed. OSLDs were irradiated to calculated dose of 1 Gy with 4 MeV standard, degraded and both degraded and collimated (2.5 cm circle) electron fields. Irradiations were performed at the depth of dose maximum (= \( z_{\text{ref}} \)) in the PMMA dosimeter blocks of IROC where the detectors had been placed at the 0.7 cm depth. For the standard 4 MeV with \( d_{\text{max}} = 0.8 \text{ cm} \), an extra 0.3 cm layer of CIRS plastic water was used. OSLDs have been calibrated by IROC using their standard procedure and American Association of Physicists in Medicine (AAPM) TG51 dosimetry protocol for electrons [12].

3. Results

The depth dose curves of 4 MeV electrons shown in the Fig. 2A are from two different linac vendors, the degraded 4 MeV beam, one modern orthovoltage device and from the idealized model, where the depth dose curve remains constant and falls instantly to zero, when
0.5 cm depth is reached. It was noticeable that Versa HD degraded 4 MeV electron beam had shortest build-up region and the fall-off region started at equal depth as the Elekta Esteya brachy device. Important was that the dose drop was faster with degraded electrons than other devices. On average the depth of dose maximum (R100) was 0.46 cm and therapeutic range (R80) 0.86 cm for all collimator sizes. As a conclusion 4 MeV degraded electron beam seemed to reach a compromise between uniform dose distribution to target and healthy tissue protection.

The Fig. 2B shows profiles for all collimator sizes at depth 0.5 cm. The field width of 80% dose from the maximum, a therapeutic field size (FS80%), was 0.2–0.3 cm less than the nominal applicator size except for the largest applicator where it was 0.2 cm larger. Penumbra (20/80) of the 2.5–5 cm collimators were equal, or slightly less than 0.5 cm for all applicators, 0.46–0.50 cm.

The differences in OFs from the IC, diode and Gafchromic® film measurements were found to be smaller than 2%. The output factors reduced significantly relative to standard 10 × 10 cm 4 MeV open field (OF = 1.000). As an example, for the 2.5 cm collimator field the OFs was only 0.127 (measured with IC) which means drop of factor 8 in output due to strong lateral scatter in the degrader plate. The drop of output was equal to factor of 7–8 for other field sizes. For OSLDs the difference between OFs in reference field size was 8% and in 2.5 cm collimator field 16.5% when compared to IC measurement. The bigger differences in OSLD OFs can be explained by the different medium and the difficulties to determine the correct field size and calibration factors for OSLDs. There may be self-attenuation, because aluminum oxide density is relatively high.

4. Discussion

The properties of developed electron applicators seem optimal for treating maximally 0.5 cm thick skin lesions. Because the properties of standard electron beam were remarkably modified, safety issues
become an important role. There is only the block coding system to prevent mixing standard electron shields with the modified applicators. Situation is critical as there is a drop by a factor of 7–8 in beam output due to the distance of PMMA filter from the skin and the scatter out of the field. We consider restricting the use of the 4 MeV beam energy with 6 × 6 applicator for only this specific application to avoid errors.

The modifications were based on the dimensions of the standard applicator. Our aim was to make as minimal changes to achieve satisfactory output. At least two variables could be optimized: size and distance of the degrader plate. Karolis et al. [7] found that degrader plates placed at the jaw face provide better beam homogeneity and steeper penumbra and are to be preferred for that reason, but also relative X-ray contamination increases, as noticed. In conclusion, this study showed that the properties of the degraded 4MeV electron beam and developed electron applicators seem optimal for treating small targets near the skin surface.

Conflict of interest

Assi Valve has received research grant from Helsinki Cancer Center. Other authors have no conflict of interest.

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