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ORIGINAL ARTICLE

Comparison of conventional inserts and an add-on electron MLC for chest wall irradiation of left-sided breast cancer

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Abstract

Background. Collimation of irregularly shaped clinical electron beams is currently based on electron inserts made of low melting point alloys. The present investigation compares a conventional electron applicator with insert and add-on eMLC-based dose distributions in the postoperative chest wall irradiation of left-sided breast cancer. *Material and methods*. Voxel Monte Carlo++ (VMC++) calculated dose distributions related to electron fields were compared with 10 left-sided breast cancer patients after radical mastectomy. The prescription dose was 50 Gy at a build-up maximum. The same dose was prescribed for the ipsilateral axillary, parasternal and supraclavicular lymph nodes that were treated with photons and calculated with a pencil beam algorithm. The insert beams were shaped with 1.5 cm thick Wood's metal electron inserts in an electron applicator of a Varian 2100 C/D linac. Doses for the eMLC-shaped beams were calculated for an eMLC prototype with 2 cm thick and 5 mm wide steel leaves. The same collimator-to-surface distance (CSD) of 5.8 cm was used for both collimators. *Results*. The mean PTV dose was slightly higher for the eMLC plans (50.7 vs 49.5 Gy, $p < 0.001$, respectively). The maximum doses assessed by D5% for the eMLC and insert were 60.9 and 59.1 Gy ($p < 0.001$). The difference was due to the slightly higher doses near the field edges for the eMLC. The left lung V20 volumes were 34.5% and 34.0% ($p < 0.001$). There was only a marginal difference in heart doses. *Discussion*: Despite a slight increase of maximum dose in PTV the add-on electron MLC for chest wall irradiation results in practically no differences in dose distributions compared with the present insert-based collimation.

Patient specific inserts made of alloys based on Wood's metal are in widespread use for shaping of clinical electron beams in the treatment of superficial targets such as the chest wall after radical mastectomy in breast cancer. The multi-leaf collimation of electron beams has been proposed as a more advanced and potentially less laborious choice. In these studies different prototype electron few-leaf [1] or multi-leaf collimators (eMLC) have been developed [2–6]. Some prototypes and related calculation methods have been aimed at modulated electron beam therapy [5,7–11]. However, so far the clinical application of the eMLC has been hampered by the lack of adequate treatment planning software and treatment delivery hardware that could support the use of eMLC collimated electrons. Only recently has electron beam therapy using a prototype eMLC for patients been reported [11].

In previous eMLC prototypes the associated electron applicator of the linac was redesigned [5,6] or removed for the installation of the eMLC [2,4]. In the latter case both fixed source-to-surface (SSD) and isocentric electron irradiations were possible [2–4]. Also the use of the photon MLC with focussed tungsten leaves has been investigated [12,13] for electron beam shaping. In this case, the patient should be positioned close to the treatment head (SSD between 70 and 80 cm) to reduce the in-air scatter of electrons leading to a prohibitive widening of beam penumbras (at typical SSDs of 100–110 cm). An alternative approach to reduce the in-air scatter of electrons and maintain the clinically relevant treatment distance (with acceptable electron contamination) would be to fill the treatment head with helium gas [13]. It has been shown that the distance from the eMLC to the treatment head has a

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marked effect on the contaminating photon dose to the patient [14,15]. If the eMLC is close to the treatment head the photon contamination is low but an increased in-air scatter of electrons results in wider penumbras of the electron beams. In contrast, by placing the eMLC close to the patient sharp dose profiles were obtained at the expense of an enhanced electron contamination near the field edges [9,16]. This is of special importance for abutting electron and photon fields such as in the radiation treatment of chest wall after modified radical mastectomy where the scar region is often treated with an electron beam and the ipsilateral axillary lymph nodes with a matched photon beam. In this study the source-to-collimator lower surface distance was 4.2 cm longer for the eMLC compared to insert (Figure 1). Based on the different geometry differences in dose distributions between the two collimators are expected.

Both leaf thickness and material have an effect on the amount of transmitted dose and also the energy and fluence distribution of electrons scattered from leaves. In the published eMLC prototypes 2.54 cm thick steel leaves [5], 1.8 cm and 3.0 cm thick brass leaves [3] and [4], and 1.6 cm thick leaves made of low melting point alloy [6] has been used. Leaves made of steel result in higher transmission of contaminating photons and a slightly wider fluence distribution compared to tungsten [5]. Also the present eMLC with 2 cm thick steel leaves [16] results in a slightly higher transmission at low electron energies compared with a 1.5 cm thick Wood's metal insert. However, this structure is expected to result in only minor differences between the dose distributions, if the maximum number of electron fields was limited to two like in this study. Focussed leaf ends with an eMLC have been reported not to offer benefit over straight leaf ends [9].

Recently, a new add-on eMLC prototype [16,17] and a new Monte Carlo (MC) beam model [18] for multi-leaf collimated electron beams were introduced. The dosimetric accuracy of the new beam model together with VMC++ dose calculation was generally within 2%/2 mm [16]. In the present investigation, the add-on eMLC of [16] as modelled by the new MC beam model and VMC++ dose calculation were applied for one of the most common electron treatments, namely chest wall irradiation of breast cancer after modified radical mastectomy. The purpose was to compare calculated dose distributions and dose-volume histograms (DVH) from the eMLC with those from conventional electron beam shaping (applicator with individual custom inserts).

Material and methods

Patients

CT-scans and digitally reconstructed radiograph (DRR) images of ten consecutive left-sided female breast cancer patients after modified radical mastectomy were the basis of the study. Previously, during 2006 and 2007 the patients had been treated at the Kuopio University Hospital (KUH) according to the local practice. Therefore, the present investigation had no influence on their treatment. The ipsilateral supraclavicular, parasternal and axillary lymph nodes were treated with an anterior or anterior and posterior 6 MV beam and the chest wall (mainly representing the operated scar region) with an individually shaped electron fields at SSD

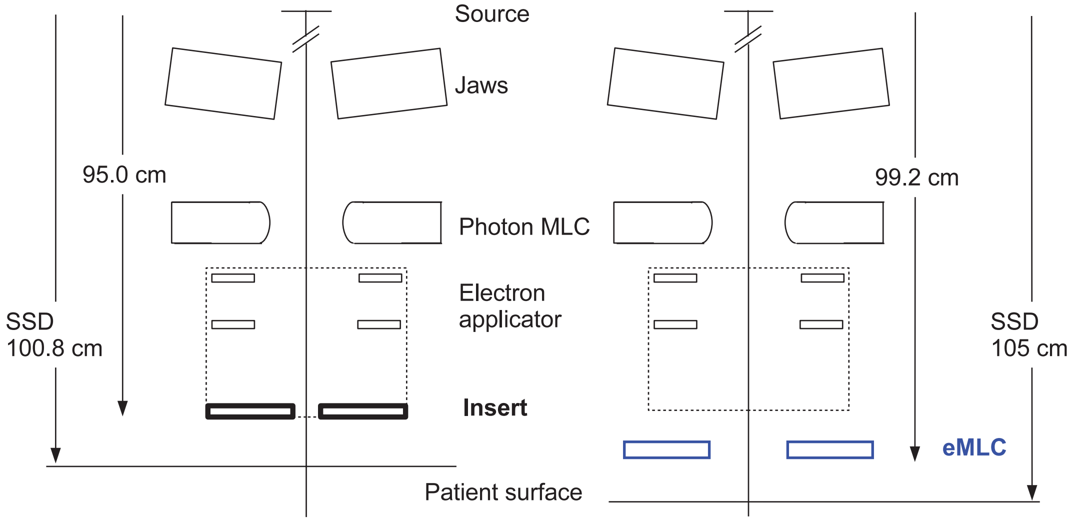

Figure 1. Schematic view of the lower part of the Varian 2100 C/D linac treatment head for the insert (left side) and eMLC geometries (right side). Also the applied treatment distance for both collimators is shown for reference.

105 cm defined by an anterior DRR image of the thorax (Figure 2). For the electron beam shaping conventional individually made electron inserts in standard electron applicators were used.

In the present study, the electron beam shapes used in patient treatments were also realized by a new add-on electron MLC prototype. The photon beams were identical in both the conventional plans (electron applicator plus insert) and the eMLC plans. Hence, the two plans compared for each patient were (i) conventional plan with one or two insert-shaped electron fields for the chest wall and one anterior or parallel opposed anterior-posterior 6 MV photon fields for the ipsilateral lymph nodes and (ii) eMLC plan with the same fields, but the electron fields collimated with the eMLC.

For a photon field shaping the standard Varian 80-leaf MLC with the projected leaf width of 1 cm at the isocenter was applied. A fixed SSD technique with SSD 105 cm for the anterior and SSD 100 cm for the posterior photon beam was used.

Treatment planning

Planning target volume and organs at risk. The PTV consisted of the chest wall from the skin to the anterior lung surface and the ipsilateral parasternal, supraclavicular and axillary lymph nodes. The mean PTV volume was then 872 cm^3 (range 596–1541 cm^3). The prescribed dose to the PTV was 50 Gy. For electron beams the prescribed dose was defined at the build-up maximum in the central part of the field according to ICRU 71. Electron beam energies (6, 9 or 12 MeV) were selected such that the therapeutic range (R_{85}) of the electron beams as closely as possible equalled or minimally exceeded the maximum thickness of the chest wall. This ensured a minimum dose of 42.5 Gy at the distal PTV surface. For photon beams the dose prescription was based on the ICRU point in the central part of the PTV. There was always a minimum dose of 45 Gy in the deepest part of the PTV in the anterior-posterior direction. For each electron and photon field the dose distribution was normalized in separate normalization points and the same normalization was used for both the insert and eMLC plans. Hence, the same dose per field was delivered at the normalization points for both plans.

Since the differences between the insert and the eMLC plans were expected to be found mainly in the high-dose regions, the PTV dose-volume parameters D5% and D10% were compared for the insert and the eMLC plans. Also the D50% volume, mean dose and standard deviation of the dose were included in the statistical analysis.

To evaluate dose to healthy tissues, the left lung and heart were defined as OARs. The V20 Gy and V30 Gy volumes were compared for the insert and eMLC plans.

Conventional electron inserts. For the electron beam shaping 1.5 cm thick individually made Wood's metal (Cerrobend®) inserts mounted in a standard 20 × 20 cm^2 electron applicator of a Varian 2100 C/D linac were used. With a standard applicator the distance from focus to the lower surface of the insert was 95 cm i.e. the collimator-to-surface distance (CSD) was 5.8 cm at the applied treatment distance (SSD = 100.8 cm). The insert aperture enclosed the

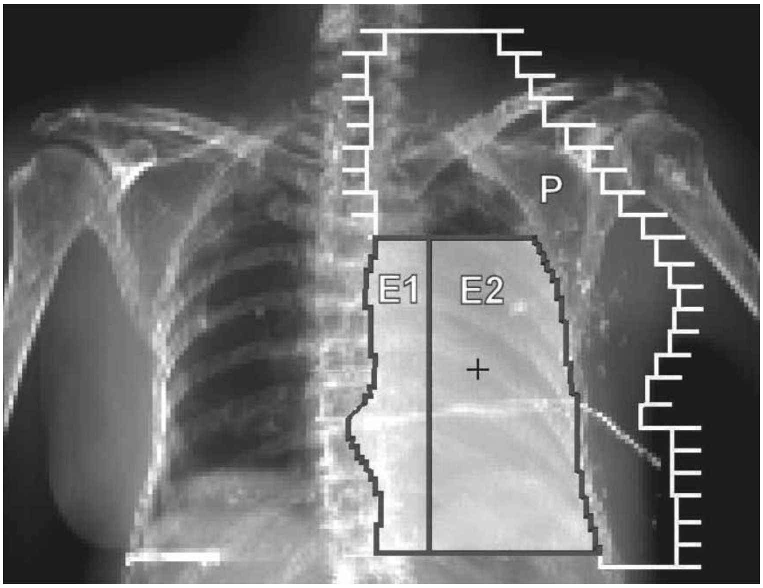

Figure 2. Beams eye-view of the chest wall irradiation with adjacent electron beams E1 and E2 together with a matched photon beam (P). The central axis is marked with (+) and the operation scar crossing the electron fields is shown with an X-ray positive wire.

PTV with a 1 cm margin. The field size was defined at the isocenter distance 100 cm, and no margin was left between adjacent fields with straight, non-diverging insert edges. The adjacent electron fields shared the same virtual source position such that the abutting field edges coincided and the isocenter was the same for both electron and photon fields.

The eMLC prototype. The electron multi-leaf collimator prototype has been described previously [16]. Briefly, the eMLC consists of 5 mm wide and 2 cm thick non-motorized steel leaves mounted in an aluminium frame. The leaf ends are straight with non-focussed sides. The prototype was attached below a standard 20×20 cm^2 electron applicator of the same linac that was used for insert beam calculations. The source-to-leaf lower surface distance was 99.2 cm which means that the CSD was 5.8 cm at SSD 105 cm. Hence, the same CSD was applied for both insert and eMLC plans. The planning beam shapes of the eMLC fields were identical to the insert-based field shaping, i.e. the center of the leaf ends was matched to the position of the insert field edge.

Dose calculations. Recently, we demonstrated that a more advanced field shaping with an add-on electron multi-leaf collimator (eMLC) could be accurately modelled using a Monte Carlo (MC) beam model together with Voxel Monte Carlo++ (VMC++) dose calculation. Electron beam dose calculations were done by the VMC++ dose calculation algorithm [19,20] implemented in a research version of the Nucletron Oncentra MasterPlan treatment planning system (version 1.5). Photon beam dose calculations were done with a pencil beam algorithm using a standard version of the TPS. The calculations for the eMLC fields were done with an extended version of the beam model implemented in a research version of the TPS. Both the insert and eMLC dose calculations were based on beam data from the same Varian 2100 C/D linac at KUH. A detailed description of the beam model for the eMLC and achieved accuracy have been published elsewhere [17,18].

The VMC++ dose calculations were performed with 5×10^4 electrons cm^{-2} sampled from the plane of the insert or the eMLC. The mean statistical uncertainty in the voxels with the dose above 50% of the maximum dose was less than 1%. Electron transport and dose scoring was done in approximately 3.3 mm cubic voxels the size of which was defined automatically by the treatment planning system without user control. Treatment planning system dose calculations were performed using a Pentium 4, 2.53 GHz single processor PC with one gigabyte of RAM.

Data analysis

The statistical analysis of the treatment plans were performed using the SPSS® version 14.0. A two-tailed statistical significance between the insert and eMLC plans was calculated using the paired samples t-test or a non-parametric Wilcoxon signed ranks test. A p-value smaller than 0.05 was considered statistically significant.

Results

In the dose distribution for the eMLC the dose was slightly pronounced near the edges of the adjacent electron fields compared to the insert plan (Figure 3a and b). Figure 4 illustrates that despite of the small differences between the plans, the higher doses for the PTV with the eMLC resulted in a slightly improved DVH.

The mean PTV and OAR doses were slightly higher for the eMLC generated plans as shown in

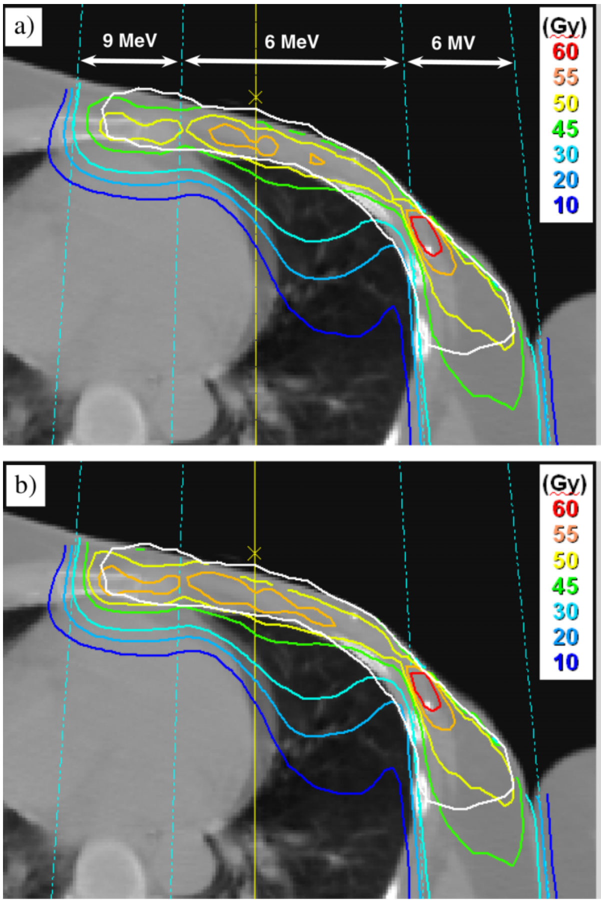

Figure 3. Electron beam dose distributions for one of the patients with 6 and 9 MeV electrons and 6 MV photons, (a) insert plan and (b) eMLC plan. The PTV is marked with a white line.

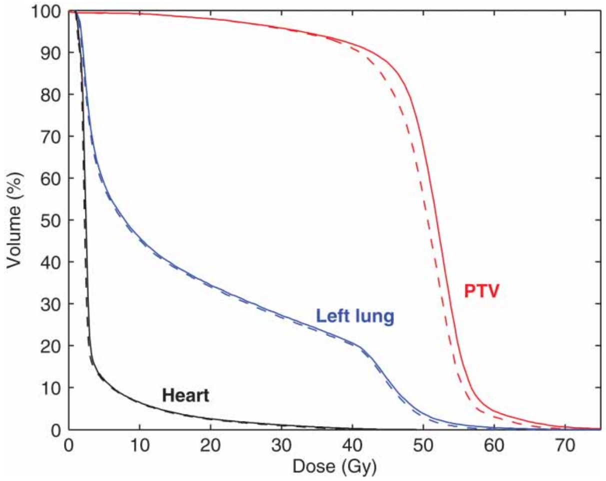

Figure 4. Dose-volume histograms for the insert (--) and eMLC (-) plans for the patient of Figure 3.

Table I. The largest differences accounting for approximately 4% of the prescribed dose were found in the mean dose and in the high dose region of the PTV (D5%, D10%). Similarly, there were statistically significant differences in the DVH parameters for lung V20 Gy and V30 Gy and with the heart which had the smallest differences between the insert and eMLC plans. For both the left lung and heart the differences were small (0.5% or less).

The mean calculation time per electron beam for the insert plans was 10.7 minutes compared to 14.8 minutes for the eMLC plans with 1% statistical uncertainty of the dose. At a 2% uncertainty level the mean calculation times decreased by a factor of more than two.

Discussion

Electron beam patient dose calculations for an add-on multi-leaf collimator prototype were compared with the conventional electron inserts in chest wall irradiation of left-sided breast cancer. The calculations were performed using dedicated beam models for both the eMLC and the insert. For the eMLC beams a new beam model [18] was used that enables accurate clinical Monte Carlo calculations for an add-on electron MLC. The accuracy of the new beam model is within 2%/2 mm when using low electron beam energies and extended SSD [16]. Similar accuracy of the dose calculations for the insert beams have been reported [21–25], which enables an accurate analysis of the differences between insert and eMLC plans.

It has previously been described that with the respective add-on type eMLC the dose near the field edges is slightly pronounced compared with a conventional applicator due to the shorter CSD [6,9,16] at SSD 100 cm. However, when applying the same CSD 5.8 cm this results in only marginal differences in PTV and OAR doses compared to a conventional electron applicator with insert (Table I). For the eMLC plans the dose was slightly higher compared to the insert plans (Figure 3a and b). This may be due to (i) different shape of the eMLC field (saw-toothed edges), (ii) different source-to-collimator distance or (iii) different thickness and material of the collimators.

The beam edges of the insert field and saw-toothed edges of the eMLC fields are slightly different. However, this is expected to result in only minor differences between the dose distributions close to the skin surface. Furthermore, the lateral scatter of electrons reduces further the effect at larger depths. Since the intensity distribution with low energy eMLC beams are smooth already at the surface [5], the saw-toothed field shape is not seen in isodoses at the dose maximum depth [9].

Using the same CSD 5.8 cm for both collimators leaves just enough space for patient positioning. However, a longer CSD (e.g. 10 cm) would likely have made the differences in penumbra and dose inside the field edge even smaller. Hence, the already slight differences in dose distributions should be even smaller at larger CSD.

In conclusion, the presented add-on eMLC results in practically no differences in dose distributions compared with the present insert-based collimation. Therefore, a replacement of inserts with eMLC is

Table I. Dose and volume differences of the DVH calculations between the eMLC and insert-based treatment plans (N=10)

	eMLC mean±SD	Insert mean±SD	Mean diff.±SD	p-value[1]
PTV D5% (Gy)	60.88±1.53	59.06±1.41	1.82±1.02	<0.001
PTV D10% (Gy)	58.11±1.53	56.74±1.16	1.37±0.87	<0.001
PTV D50% (Gy)	51.99±1.17	50.82±0.97	1.17±0.68	<0.001
PTV mean dose (Gy)	50.68±0.90	49.47±1.01	1.21±0.66	<0.001
left lung V20 Gy (%)	34.51±8.31	34.02±8.37	0.48±0.21	<0.001
left lung V30 Gy (%)	28.66±7.25	28.16±7.26	0.51±0.18	<0.001
heart V20 Gy (%)	3.43±3.42	3.28±3.22	0.14±0.11	<0.01
heart V30 Gy (%)	1.53±1.92	1.42±1.91	0.11±0.11	<0.01

[1] for the paired differences

potentially feasible. A remotely controlled eMLC device with adequate software would facilitate these kinds of treatments. However, issues related to the clinical implementation of the eMLC such as mounting of the eMLC, collision avoidance and quality assurance need to be further studied.

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