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IMRT/VMAT dose distributions generated for *HD*® and *Millennium*® collimators *TrueBeam*® and *Clinac*® accelerators

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ABSTRACT

Aim: The aim of this study is to answer the question whether the calculated dose distributions for HD and Millennium collimators (Varian Medical Systems) are equivalent for large treatment volumes.

Background: Modern biomedical linacs are equipped with multileaf collimators where leaves can be of different widths. Thinner leaves allow better fit to desired (tumor) shape. At the same time, however, the maximum size of the field that can be obtained with the collimator is also reduced. Varian Medical Systems HD and Millennium collimators can be a good sample. They have 40 cm or 22 cm × 40 cm maximal field size at the isocenter, respectively.

Materials and methods: This paper presents the comparison of selected statistical and dosimetric parameters achieved for treatment plans where the beams for a HD collimator had to be merged because of the size of the tumor volume.

Results and discussion: Achieved results show that, independently from irradiated volume, there is no statistically significant difference for calculated dose distributions, integral doses, MU values and coefficients evaluating dose distributions for HD and Millennium collimators.

Conclusions: Results show that both types of collimators can be used interchangeably for preparing the treatment plans for large tumor volume without quality reduction of the prepared treatment plan.

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1. Background

In the nineties of the twentieth century, new biomedical Linacs with multileaf collimators (MLC) were implemented in radiotherapy. Those collimators generate cross-section fields, adapted to the desired shape[1] of the tumor with proper margin visible in a perpendicular plane to the beam axis. Using MLC for individual shaping of irradiation fields and image data allows three-dimensional dose distribution reconstruction and is defined as conformal radiotherapy (3D - CRT).[2,3] Individual shields were used to adjust fields size (shape) to tumor shape before MLC was implemented. Shields were made from proper material, mostly Wood's alloy. Due to individuality of the shields (for each patient and each field there was a different shield), preparation of the patient to radiotherapy was very time-consuming and it could have taken even several days.[3] Furthermore, during a treatment session for each irradiation field, the shield had to be replaced because of tumor shape changes caused by a different direction of the beam's entry (to the patient body). MLC usage enables automatic shaping of irradiation field which significantly reduced treatment time[4] and the number of entrances to the bunker. The MLC disadvantage for static fields is the inability to shield a part of the cross section of the beam in such an area that a shielded area is surrounded by a radiation field.[3] In this case, it is necessary to use an appropriate fixed shield. It is also important to keep in mind that any shape of the beam has its discrete limits associated with the width of collimator leaves. The width of the first leaves used in MLC was 10 mm, that means a width of the shadow cast by a single leaf at an isocenter distance and this is how the "width of a leaf" has to be interpreted in this paper. In effect, the field shape was "discreet", not continuous (Fig. 1). It was a problem to precisely fit a beam size to a tumor shape. Over time, the width of the leaves was decreasing and it allowed a more precise fit of the beam's shape to the desired shape of the tumor (Planning Treatment Volume projection on the perpendicular plane to the beam axis). It should be considered that each leaf has its own electric engine, so with the increase of the number of leaves, the number of engines also increases. For example, the maximum size of the beam in the isocenter for standard Linac collimator is 40 cm by 40 cm, which for 10 mm leaves requires 40 engines for one side of the collimator, but for 2 mm leaves there has to be 200 engines on one side, which gives 400 engines for both sides of the collimator. Therefore, the maximum size of the beam for collimators with 2 mm leaves is smaller than for 10 mm leaves.

Modern biomedical linacs are equipped with HD (High Definition) multileaf collimators where leaves are 2.5 mm wide in the isocenter and they can be used to irradiate very small tumors (for example in radiosurgery). Benefits result in some limitations associated with the maximum size of radiation beam. In the case of HD collimators, they are twice as small as Millennium collimators (5 mm leaf width in isocenter). For both type of collimators, the leaves number is the same, 60 leaves on one side; however, due to leaves width, the maximum size of the field for Millennium MLC is 40×28 [cm $\times$ cm] and for HD MLC: 22×28 [cm $\times$ cm]. In clinical practice it causes some difficulties, the largest linear dimension of the irradiation volume often exceeds 22 cm (Fig. 2).

To irradiate a big volume, there is a need to use several beams with different centering points (folding beams). It requires a very precise and well thought planning methodology. The slightest shift of the beams toward each other can lead to decreasing or increasing the dose (in this case it is not so significant). However, the dose reduction in the irradiated volume could lead to the reduction of local cure probability. The question is whether they can be used to irradiate large volumes without reducing dose distribution uniformity in the treated volume.

If an oncology center decides not to equip its linacs in HD MLC then irradiation of very small tumors (e.g. radiosurgery) will not be possible.

HD collimators are designed/dedicated mainly to irradiate relatively small tumors, because of leaves width. Application

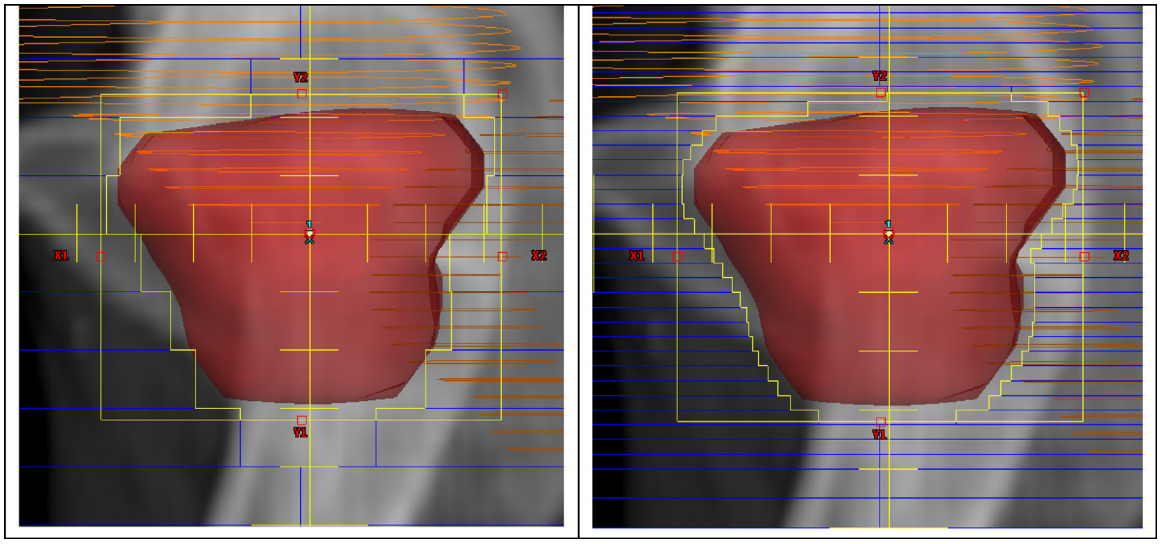

Fig. 1 – Collimator with 1 cm-wide leaves (left panel) quite well limits the treatment area to the area of the tumor, but the 2.5 mm-wide leaves (right panel) cover it in a much better way.

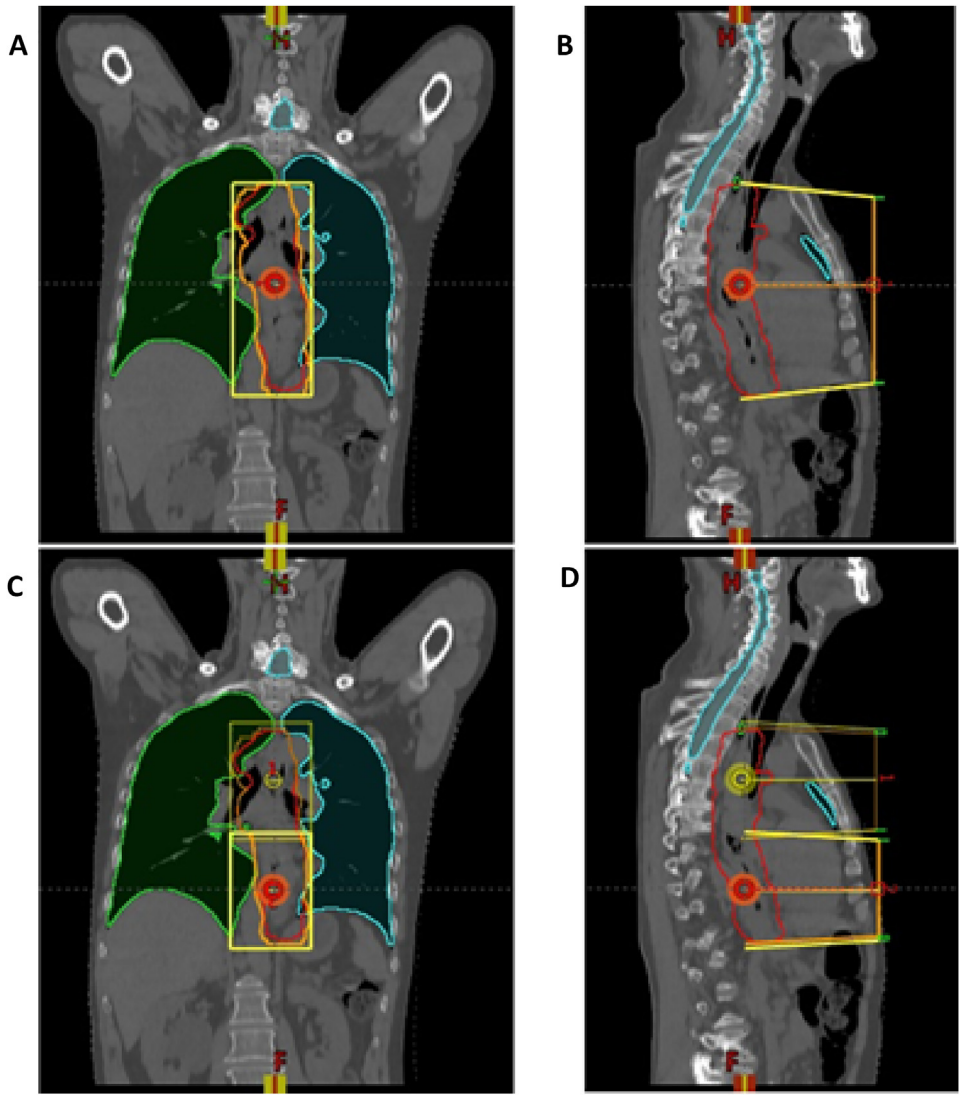

Fig. 2 – An example of a planned treatment volume whose linear dimension exceeds 22 cm. With Millennium collimator, one radiation beam (A, B) can be used, which covers the entire tumor. If HD collimator is available, at least two radiation beams (C, D) are necessary to cover the entire volume of the tumor. It should be noted that the use of several beams causes the appearance of the bonding area, which requires special attention in the computerized planning of the dose distribution.

of an HD collimator for large tumors does not improve the dose distribution. The problem appears if Planning Treatment Volume (PTV) are larger and hospital is equipped only with HD collimators with their maximal field size limited to 22 cm. According to Shepard,[5] for collimators equipped with leaves of 2 mm and 4 mm width (the closest values of real leaf width of HD and Millenium, respectively), the differences seem not to be very important (Table I, Table II and Table V from the paper). In addition Shepard et al. investigated relatively low nominal energy (maximal values were 2 and 4 MeV), which could cause different lateral electron scattering and finally some averaging effect in the dose distribution for the treatment plans with higher energy.

2. Aim

The aim of this study is to answer the question whether the calculated dose distributions, for HD and Millennium collimators (Varian Medical Systems) are equivalent for large treatment volumes.

3. Materials and methods

Irradiation techniques of the chest wall or pelvis require large fields. If a therapeutic field is too large to use HD MLC then two or more centering points must be applied. During therapy patient and couch shift is required to place the centering point in the isocenter.

In this paper 19 patients irradiated using Millennium MLC (photon energy: X – 6 MV, X – 10 MV with and without a flattened filter) with large tumors (breast, esophagus, abdomen cancer) were taken into account. Dose (100%) was defined at Primary Reference Point which was chosen in a homogeneous PTV area. Next, according to previous assumptions, dose distributions for HD MLC were calculated.

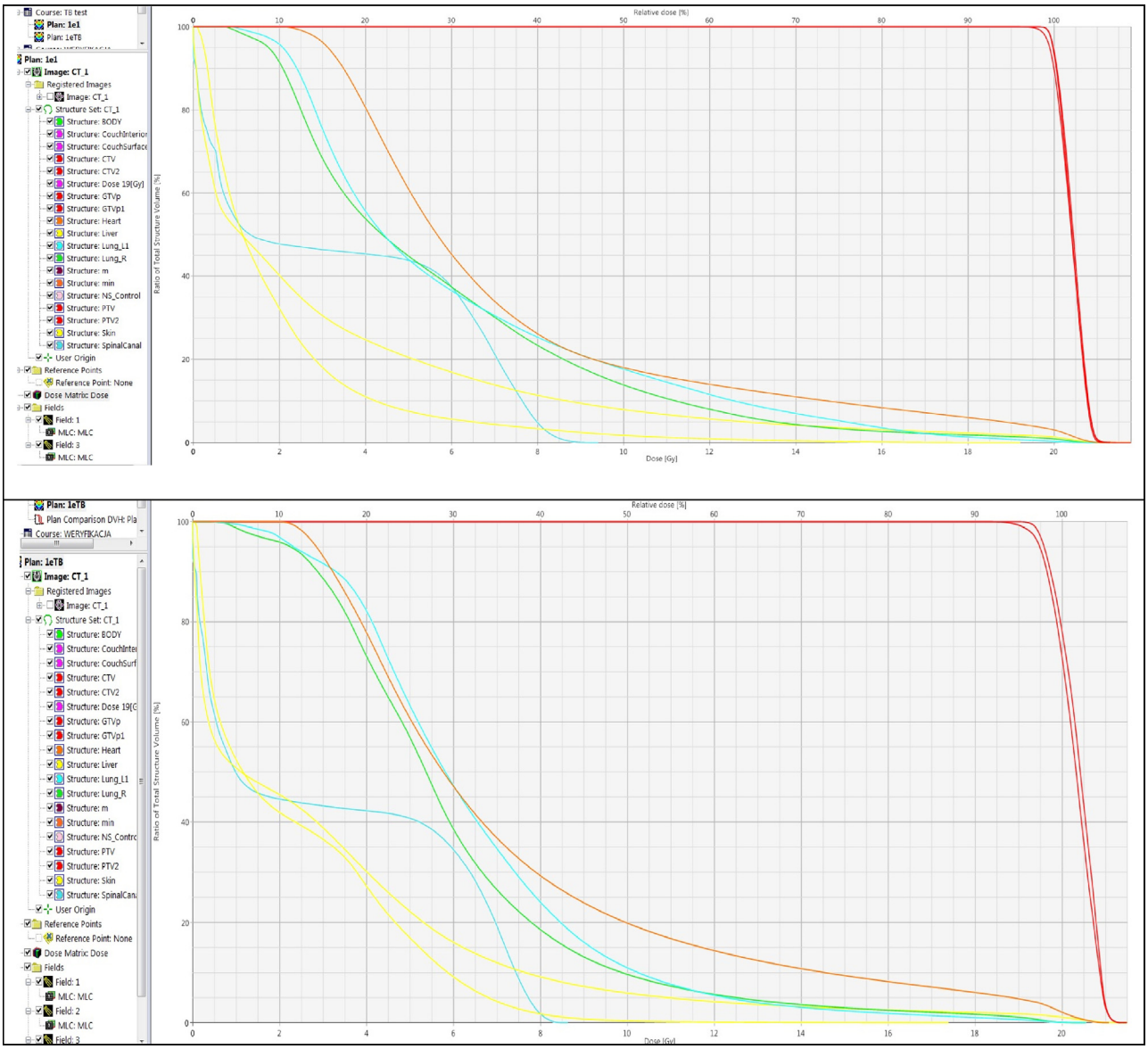

Fig. 3 – Histograms of the dose distributions and tabularized corresponding parameters calculated for Clinac with Millennium collimator (A) and TrueBeam HD collimator (B). All statistics on the dose distribution are available from the chart: minimum, mean, modal, median, and standard deviation values.

Following parameters were statistically evaluated: coefficients evaluating dose distributions (CI – Conformity Index,[6,7] GM – Gradient Measure,[6,7] RPI – Radiation Planning Index [8]), Monitor Units (MU) number and dose values: Integral,[6,7] Minimum, Mean, Modal, Median and Standard Deviation. For each patient, the above values were determined from Dose Volume Histogram (DVH) according to the dose distributions calculated for Varian Medical System HD and Millennium MLC (Fig. 3).

To evaluate the compatibility between the analyzed data sets, non-parametric tests for independent samples were used: the Wald–Wolfowitz series test and *U* Mann–Whitney test (due to a small group of patients) where distribution continuity was taken into account. Statistically significance level was set at 0.05.[9–13]

4. Results

Analysis was performed for 19 patients. Based on tumor location, this group was divided into subgroups: breast – 8 cases, gynecology – 5 and one case for: the larynx lymph nodes, spleen, esophagus, abdomen, lymphatic system and pelvis. Mean equivalent radius of treated volumes was 5.3 cm (V – 633 ppm), mean number of the beams for Millennium MLC was 6.7, for HD MLC – 8.3.

Table 1 shows mean dose values in anatomical structures for all analyzed patients, for Millennium and HD MLC. Statistical differences between them were checked by the *U* Mann–Whitney and Wald–Wolfowitz non-parametric tests using Statistica ver. 12 software.

Table 1 – Average dose values for sample patient and anatomical structures for Millennium and HD collimators. These were the basis for performed comparison, whether there is a statistically significant difference between them.

Patient	Treatment area	Structure	Millennium	HD
X	Lymphatic system	Rectum	0.17	0.34
		PTV	20.13	20.30
		Intestines	6.62	6.89
		Right femur head	0.06	0.12
		Left femur head	0.08	0.15
		CTV	20.24	20.30
		Bladder	0.16	0.31
		Spinal canal	7.67	8.22
		Right kidney	6.02	6.16
		Left kidney	6.00	6.11
		Liver	4.09	4.20
		Skin	2.67	2.81

Table 2 – Significance values for the Mann–Whitney *U* test (corrected for continuity) for RPI, Cl, GM, ID, MUs.

Compared parameters	Rang sum		Significance "*p*" value
	Millennium	HD	
RPI	382,000	359,000	0.748
CI	329,500	336,500	0.924
GM	327,000	339,000	0.861
ID	367,000	373,000	0.941
MUs	372,000	369,000	0.976

Table 3 – Significance values for the Wald-Wolfowitz test for minimum, average, maximum, median and modal doses.

Compared parameters	Rang sum		Significance "*p*" value
	Millennium	HD	
Minimum dose	14.982	13.995	0.807
Mean dose	22.247	22.318	0.818
Maximum dose	40.272	39.686	0.807
Modal dose	21.846	21.504	0.087
Median dose	23.213	22.732	0.684
SD	5.7053	6.0084	0.222

Table 2 contains results of statistical analysis of the RPI, CI, GM, ID and MU coefficients compatibility. Table 3 contains minimum, mean, maximum, modal and median dose. Performed calculations show that sets of coefficients, mentioned above, for Millennium and HD MLC do not indicate statistically significant differences on significance level $p = 0.05$.

Mean values of analyzed dose distributions coefficients were calculated. It was found that differences between them were less than 5% (in relation to values received for Millennium MLC), except MU values, where difference was 16%. For HD MLC MU, the value was bigger because more fields were used. Therefore, this difference is not statistically significant (Table 2) and does not contribute to the increase of integral dose (Table 4).

Table 4 – Mean values of the analyzed dose distribution parameters for Millennium and HD collimators.

Parameters	MLC	
	Millennium	HD
Minimum dose [Gy]	13.586	13.144
Mean dose [Gy]	19.184	19.312
Modal dose [Gy]	18.482	18.388
Median dose [Gy]	19.756	19.669
Maximum dose [Gy]	34.426	34.264
SD	4.448	4.538
MU	1308.316	1517.737
Integral dose [Gy cm^3]	9.280	9.338
RPI	0.432	0.417
CI	1.097	1.107
GM [cm]	4.157	4.365

Calculations of the dose distributions and their statistical analysis show that the dose distributions calculated for Millennium MLC with leaves of 5 mm width and HD MLC with leaves of 2.5 mm (in isocenter) width allow to obtain comparable dose distributions for large treatment volumes. In some cases, organs at risk are adjacent to the tumor and then collimators with leaves of 2–3 mm width allow more precise beam adjustment to the tumor simultaneously protecting normal tissues.

For example, in the article[14] treatment plans performed for a standard collimator with 1 cm-wide leaves and micro collimator with 3 mm-wide leaves were compared. For each of the compared techniques and calculation algorithms, dose distributions were statistically better if micro collimator was used. In the paper[13] dose distributions for four types of collimator were compared. For each treatment plan, the best parameters of target (tumor) coverage were for the collimator with the thinnest leaves. The authors of other papers[15,16] also pointed to a better protection of organs at risk in treatment plans where micro collimators were used. Unfortunately, the consequence is that maximum dimension of the beam's side is relatively small e.g. BrainLab micro collimator – 10 cm,[17] Varian Medical System HD MLC – 22 cm.[4]

There is not much data on these issues in the literature and available publications generally describe the linking of the treatment fields in breast cancer for standard collimators.[18–20] In the case of the radiosurgery technique in brain cancer, maximum field dimension of several centimeters are sufficient. In standard radiotherapy, fields size of 22 cm could be sufficient if treated volumes have a spherical shape but more often the shape is different (Fig. 2). All analyzed patients in this work were treated using Millennium MLC, because of the volume size which was greater than 22 cm. It can be concluded that irradiation of the tumor with lymph nodes requires the application of the beam size greater than 22 cm. So, it is important to answer the question whether the use of several smaller beams provides comparable dose distributions. If the dose distributions are comparable, what about integral doses and MU values. Are they comparable? Performed calculations indicate that regardless of the irradiated volume (head and neck, mediastinum, abdomen) dose distributions (rated based on CI, GM, RPI coefficients), integral doses and MU values did not show statistically significant difference between distributions generated by HD MLC and Millennium MLC. The fact is that

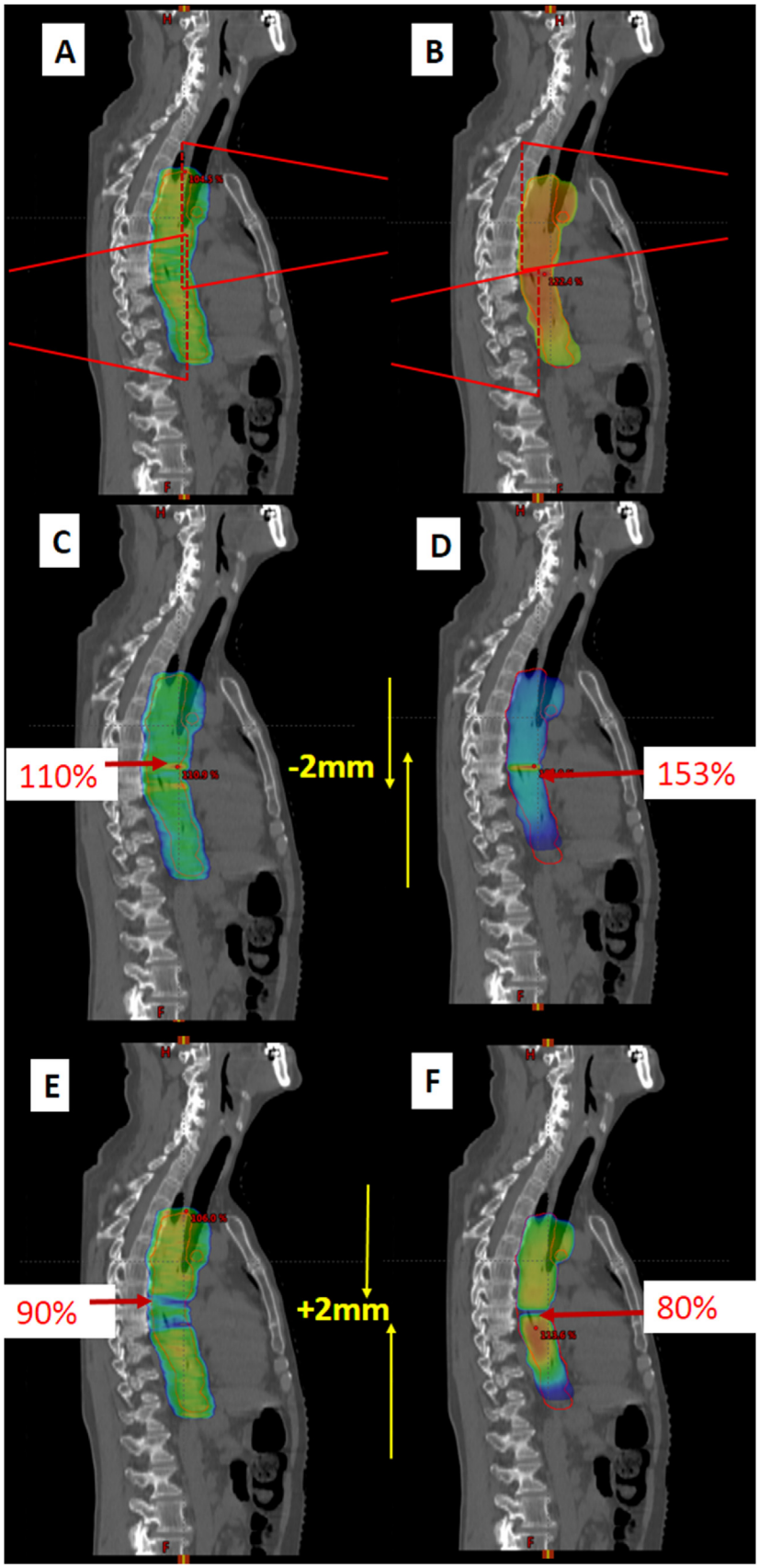

Fig. 4 – Dose distribution for VMAT (A) and box (B) techniques without isocenters shift, according to the treatment plan. Dose distributions are acceptable for both techniques. 2 mm isocenter shift which causes beam overlapping increases the dose by 10% for the VMAT (C) and 53% for box (D) technique. Distance greater than 2 mm between two isocenters causes dose decreasing by 10% for the VMAT (E) and 20% for the box (F) technique.

treatment time is slightly longer if HD MLC is used because of the large number of beams, but this difference is not statistically significant. Of course, using HD MLC allows for more precise fit of the beam shape to the shape of the tumor.

Multi-isocenter techniques may cause a too high or too low dose to occur in the beam overlapping region. For the dynamic RT techniques (e.g. IMRT/VMAT), this is a minor problem because of the use of the partial imposition of neighboring beams (Fig. 4), 2 mm shift has very slight influence on over- or underdose in the region, contrary to the non-dynamic techniques/static fields.

Summarizing, in clinical practice Millennium MLC can be replaced by the HD MLC.

5. Discussion

Performed statistical analysis shows no statistically significant differences between dose distributions calculated for big size tumor volume for HD and Millennium MLC. However, selection of a particular type of collimator is associated with certain consequences. If more precise HD MLC is selected, then treatment time is longer due to the complexity of a treatment plan where two or more isocenter points were used. Compatibility of the dosimetric model of linac's gantry with measurements, its repeatability and accuracy of collimator jaws setup is important in the case of field merging. The significant matter is how to change the isocenter during therapy (automatic or manual couch shift by the value based on a treatment plan or under control of the daily patient setup) and the patient setup verification in the position of a new isocenter. If two types of collimator are available it should be carefully considered which one is better in a particular case. On the one hand, it is possible to achieve a better fit of the beam shape to the desired tumor shape, but the fields merging issue should be kept in mind. On the other hand, using Millennium MLC gives a worse fit of the beam shape to the tumor volume, but the treatment time is shorter and there is no doubt according to the fields merging issue. Possibility of replacing Millennium MLC by HD MLC (possibility of large volume irradiation) and obvious increasing the conformity of the dose distribution in the irradiation area (leaf width) support the usage of HD MLC not only for stereotactic cases and conventional large volume irradiations but also in non-standard cases. For example, a benefit in dose distribution could be observed in dose painting and simultaneous integrated boost methods (e.g. prostate or head and neck cancers) or during irradiation of large PTV that needs reduction of dose in internally-placed organ at risk (brain irradiation with hippocampus sparing).[21,22]

6. Conclusions

Calculations of dose distributions and their statistical analysis show it is possible in clinical practice to use MLC-HD in the treatment of large PTV. Only the number of monitors units is bigger for collimator HD in comparison to MLC Millennium.

Conflict of interest

None declared.

Financial disclosure

None declared.

REFERENCES

1. Brewster L, Mohan R, Mageras G, et al. Three dimensional conformal treatment planning with multileaf collimators. *Int J Radiat Oncol Biol Phys* 1995;**33**(5):1081–9.
2. *Transition from 2-D radiotherapy to 3-D conformal and intensity modulated radiotherapy*. Vienna: IAEA-TECDOC-1588; 2008.
3. Boyer A, Biggs PJ, Chang S, et al. *Basic application of multileaf collimator*. Madison, WI: AAPM report no 72; 2001.
4. Jeraj M, Robar V. Multileaf collimator in radiotherapy. *Radiol Oncol* 2004;**38**(3):235–40.
5. Shepard, Olivera G, Angelos L, et al. A simple model for examining issues in radiotherapy optimization. *Med Phys* 1999;**26**(7):1212–21.
6. https://www.varian.com/sites/default/files/resource_attachments/TrueBeamBrochure_RAD10119D_September2013.pdf.
7. *Eclipse photon electron reference guide, P1008621-001-A*. Varian Medical Systems; 2014.
8. Ślosarek K, Grządziel A, Szlag M, Bystrzycka J. Radiation Planning Index for dose distribution evaluation in stereotactic radiotherapy. *Rep Pract Oncol Radiother* 2008;**13**(4):182–6.
9. Brahme A. Dosimetric precision requirements in radiation therapy. *Acta Radiol Oncol* 1984;**23**(5):379–91.
10. D'Arienzo M, Masciullo SG, Sanctis V, et al. Integral dose and radiation-induced secondary malignances: comparison between stereotactic body radiation therapy an three-dimensional conformal radiotherapy. *Int J Environ Res Public Health* 2012;**9**(11):4223–40.
11. Mann H, Whitney D. On a test of whether one of two random variables is stochastically larger than the other. *Ann Math Stat* 1947;**18**(1):50–60.
12. Wilcoxon F. *Some rapid approximate statistical procedures*. Stanford, CT: Stamford Research Laboratories; 1949.
13. Wald A, Wolfowitz J. An exact test for randomness in the non-parametric case based on serial correlation. *Ann Math Stat* 1943;**14**(4):378–88.
14. Dvorak P, Georg D, Bogner J, et al. Impact of IMRT and leaf width on stereotactic body radiotherapy of liver and lung lesions. *Int J Radiat Oncol Biol Phys* 2005;**61**(5):1572–81.
15. Nill S, Tücking T, Münter MW, et al. Intensity modulated radiation therapy with multileaf collimators of different leaf widths: a comparison of achievable dose distributions. *Radiother Oncol* 2005;**75**(1):106–11.
16. Kubo H, Wilder R, Pappas C. Impact of collimator leaf width on stereotactic radiosurgery and 3D conformal radiotherapy treatment plans. *Int J Radiat Oncol Biol Phys* 1999;**44**(4):937–45.
17. Monk J, Perks JR, Doughty D, et al. Comparison of a micro-multileaf collimator with a 5-mm-leaf-width collimator for intracranial stereotactic radiotherapy. *Int J Radiat Oncol Biol Phys* 2003;**57**(5):1443–9.
18. Bortfeld T, Schlegel W, Höver K-H, et al. *Mini and micro multileaf collimators*. https://www.aapm.org/meetings/99AM/pdf/2796-50260.pdf.

19. Miles E, Venables K, Hoskin PJ, et al. Dosimetry and field matching for radiotherapy to the breast and supraclavicular fossa. *Radiother Oncol* 2009;**91**(1):42–8.
20. Zhang T, Dilworth JT, Marina O, et al. A three-field monoisocentric inverse breast treatment planning technique without half-beam blocking. *J Appl Clin Med Phys* 2015;**16**(5):246–58.
21. Skórska M, Piotrowski T, Ryczkowski A, Kazmierska J. Comparison of treatment planning parameters for dose painting head and neck plans delivered with tomotherapy. *Br J Radiol* 2016;**89**:20150970.
22. Tarnawski R, Michalecki L, Blamek S, et al. Feasibility of reducing the irradiation dose in regions of active neurogenesis for prophylactic cranial irradiation in patients with small-cell lung cancer. *Neoplasma* 2011;**58**: 507–15.