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The modified inverse hockey stick technique for adjuvant irradiation after mastectomy

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Aim. *To present the technique of irradiation of post-mastectomy patients used in the Holycross Cancer Centre in Kielce.*
Material and methods. *The paper presents a detailed description of the technique which is referred to as the "modified inverse hockey stick technique (MIHS)". The dosimetric characteristic of dose distribution for the MIHS technique is presented basing on dose distributions calculated for 40 patients. The measurements used to evaluate dose distribution included standard deviation of the dose in the Planning Target Volume (PTV) and the percentage of the PTV volume receiving a dose larger than 110% and smaller than 90%; the lung volume received at least 20 Gy (LV20) and the heart volume received at least 30 Gy (HV30). The distribution of the electron beam energy is also presented.*
Results. *The standard deviation of the dose in the PTV was approx. 10% in a majority of patients. About 12% of the PTV volume received a dose more than 10% smaller than intended and about 10% of the PTV volume received a dose more than 10% greater than intended. For patients irradiated on the left side of the chest wall the LV20 was always lesser than 25% and for patients irradiated on the right side of the chest wall – always less than 35%, except for one patient, in whom it reached 37%. The HV30 was always below 8%.*
Conclusions. *The MIHS technique is a safe and reliable modality. The main advantages of the technique include very convenient and easily repeated positioning of the patient and small doses applied to the organs at risk. The individually calculated bolus plays an important role in diminishing the dose to the lung and heart. The disadvantages of the technique include poor dose homogeneity within the PTV and long matching lines of the electron and photon beams.*

Zmodyfikowana technika „odwróconego kija hokejowego" stosowana do napromieniania pacjentek po mastektomii

Cel pracy. *Zaprezentowanie techniki napromieniania pacjentek po operacji odjęcia piersi, stosowanej w Świętokrzyskim Centrum Onkologii.*
Materiał i metody. *Przedstawiono szczegółowy opis techniki, którą określono jako zmodyfikowaną technikę odwróconego kija hokejowego. Przedstawiono ilościowe wyniki obliczeń rozkładu dawki dla 40 pacjentek. Rozkład dawki scharakteryzowano poprzez: odchylenie standardowe dawki w Zaplanowanym Obszarze do Napromieniania (PTV), objętość PTV, która otrzymała dawkę wyższą o ponad 10% od zaplanowanej i objętość obszaru, który otrzymał dawkę niższą od zaplanowanej o ponad 10%. Ponadto obliczono objętość płuc, które otrzymały dawkę ponad 20 Gy oraz objętość serca, które otrzymało dawkę ponad 30 Gy.*
Wyniki. *Odchylenie standardowe w PTV wynosi około 10% dawki zaplanowanej. Około 12% PTV otrzymuje dawkę o ponad 10% niższą od zaplanowanej, a 10% dawkę wyższą od zaplanowanej o ponad 10%. Dla pacjentek napromienianych po prawej stronie dawkę ponad 20 Gy otrzymuje nie więcej niż 35% objętości płuc. U jednej pacjentki wartość ta wynosi 37%. Po lewej stronie objętość płuc nigdy nie przekracza 25%. Dawkę powyżej 30 Gy otrzymuje najwyżej 8% serca.*
Wnioski. *Prezentowana technika jest bezpieczna i ma wiele zalet. Podstawowe jej zalety to wygodne, odtwarzalne ułożenie leczonych chorych oraz niskie dawki w narządach promieniowrażliwych. Zastosowanie indywidualnego bolusa ma istotny wpływ na obniżenie dawki absorbowanej w płucach i sercu. Wadami techniki jest mała jednorodność rozkładu dawki w PTV oraz długa linia łączenia wiązki fotonowej z elektronową.*

Key words: post-mastectomy irradiation technique, treatment planning, dose distribution
Słowa kluczowe: technika napromieniania po mastektomii, planowanie leczenia, rozkład dawki

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Introduction

Adjuvant postmastectomy teleradiotherapy is standard treatment among breast cancer patients at high risk of locoregional recurrence [1, 2]. Despite a long history of irradiation in patients after mastectomy, only recently survival benefits have been proven in randomized trials [3, 4]. The main drawback of radiotherapy in breast cancer departments was a considerable excess of cardiac deaths noted in the irradiated patients [5-7]. Patients with left-sided tumors had a higher probability of developing coronary heart disease than those with right-sided tumours. Previous techniques caused a large volume of the heart to be included in the high dose region, which, when combined with inappropriate fractionation was considered to be the main causes for high cardiac mortality. However, adequate techniques and fractionations did not affect this toxicity [4, 8]. The dose to the heart depends on the technique applied, the energy and type of radiation used for the treatment. The highest dose to the heart used to be delivered in the era of orthovoltage and cobalt radiotherapy, when the so-called wide tangent technique was used irrespective of the radiation type. The second important dose-limiting organ for radiation therapy of the breast is the lung [9-12], although significant lung injury, i.e. radiation pneumonitis and fibrosis, was reported very rarely, mainly in patients previously treated with systemic therapy [13]. Better understanding of the dose-volume relationship causing lung and heart injury, as well as parameters that can easily be obtained from dose-volume histogram curves, help in the evaluation of dose distribution in the treatment plans prepared for each individual patient. Breast cancer is the most common malignancy in women, and therefore the application of a reliable and safe treatment technique is of particular importance. There exists a very large number of techniques used for postmastectomy irradiation: a) the most common technique based on two tangential opposite beams, b) very modern IMRT techniques with or without active breathing control, c) several electron based techniques, stationary and arc techniques, d) complicated rotational photon techniques and e) mixed photon and electron techniques. Nevertheless, no single technique is accepted as the „gold standard" [14-19]. The choice of the technique applied in each radiotherapy department depends on its technical possibilities, preferences and traditions. The aim of this paper is to describe the postmastectomy irradiation technique of breast cancer patients applied in the Holycross Cancer Centre (HCC) in Kielce. Our technique is referred to as the modified inverse hockey stick technique (MIHS), because of the shape of the blocks used, i.e. resembling a hockey stick. This technique has been applied for many years in Aarhus in Denmark [20]. The paper presents the modified HIS technique, which is in routine use in the Holycross Cancer Centre. The quantitative characteristic of dose distribution for a group of patients is given.

Material and method

Patients

For dosimetric purpose the study group consisted of 40 women suffering from breast cancer, treated with adjuvant postmastectomy radiotherapy directed to the chest wall and loco-regional lymph nodes. The indications for postoperative irradiation were: histologically confirmed involvement of excised axillary lymph nodes (pN+) and/or tumor stage pT3 or pT4 revealed in the pathology report after radical mastectomy. Patients previously diagnosed as stage III, who were subjected to neoadjuvant preoperative chemotherapy were also referred for postmastectomy radiotherapy irrespective of the findings within pathology specimen. Irradiation was carried out together with systemic adjuvant treatment. Radiotherapy was usually started immediately after cycle 2 of CMF chemotherapy, with cycle 3 given concomitantly with irradiation. In patients for whom an antracyclin based regimen was prescribed, postmastectomy radiation was postponed until the end of this treatment. In case of adjuvant hormonotherapy, postoperative radiotherapy was initiated when the healing of the surgical wound was adequate. In the evaluated group there were 23 patients irradiated on the left side and 18 patients irradiated on the right side of the chest wall. The treatment plans of the patients were renumbered for the use of this article: 1-23 stands for left-sided patients and 24-42 – for right sided patients.

Data processing for treatment planning

All data needed for the treatment planning was collected in the treatment position. The patient was lying supine on a flat table with both arms along the body. The arm on the treated site was slightly abducted, so as not to touch the chest wall in the irradiated region. In order to render the treatment position as comfortable as possible, the KneeFix (SINMED) immobilization system was used. Patient position is shown in Figure 1. Two tattoos – BL and BR were made in accordance with the external laser system on both lateral surfaces of the thorax. A third point – the GR – was tattooed on the frontal surface of the thorax at the mid-line, near the sternum. This point was used as a geometrical reference point for indicating the entrance for both photon and electron beams. All three points were used to repeat the position of the patient during the irradiation. At the time of the CT scanning, small radio-opaque wire crosses were placed on the patient's skin at GR. The scar was marked with a thin wire. CT images were acquired at 10 mm thick intervals from the level of the mandible through the lung bases. The CT images were transferred to the contouring station where the

Figure 1. The positioning of a patient for HIS technique

CTV and organ at risk contours were delineated by radiotherapists.

The lung contours were defined by means of an automated density gradient tracing method and, if necessary, corrected by the physicists responsible for treatment planning. The heart contours were delineated manually by physicians. The CTV – including the chest wall, the axillary, parasternal and supraclavicular lymph nodes – was entered by a radiotherapist. The PTV was defined by expanding the CTV by 5 mm in the medio-lateral direction only. This margin was to compensate the set-up errors only. Then the data was sent to the treatment planning system the TMS Nucletron Ver.6.0. The PTV and organs at risk were checked and corrected by a senior radiotherapist before the onset of treatment planning.

Treatment planning

A typical treatment field arrangement is shown in Figure 2. The dashed region is covered by a block for photon field and at the same time it is an electron field.

In most cases, one AP 6 MV photon and one AP electron field of individually chosen energy was used. The energy of the electron beam was chosen from 6, 9, 12 and 15 MeV. The supraclavicular and axillary regions were irradiated with the photon field only. The chest wall was irradiated with photon and electron fields. There was no fixed position of the upper (superior) border of the electron beam. The position of this edge was defined during treatment planning. Most often the edge was located near the second rib. The lateral border of the electron beam and, consequently, the medial edge of the photon block were located a few millimeters internally from the lung-chest wall edge. The lateral edge of the electron field was shaped individually with an inversed hockey stick-shaped block. For the photon field, the part of the PTV, which was irradiated by electron beam, was covered by a shielding block. The photon and electron blocks matched each other – there was no gap between two fields.

The energy of the electron field was chosen individually for each patient. The dose in the therapeutic region covered with the electron field could not be lower than 85% of the maximum dose at the central axis. The only exception to this rule was that at the upper border of the electron field the minimum dose was allowed to be of 80%. Preferably, the minimum dose should be 90%. This requirement influenced the decision as to where to place the upper border of the electron field. In order to spare the lung tissue and the heart in left-sided patients, the highest energy of the electron beam was 15 MeV. If the chest wall thickness required the usage of a higher energy electron beam, a standard tangential photon field technique was preferred [18].

The treatment planning process usually began with the choice of the energy of the electron beam. Then the shape of the electron field was designed. After that, the size and the shape of the photon field were chosen. The dose distribution was calculated and the first preliminary design of the individual bolus was started. The first suggestion of a bolus shape bases on the therapeutic range of the electron beam. The thickness of the bolus and the underlying tissue along the beam ray is equal to the therapeutic range of the electron beam. The dose distribution was calculated and reviewed by a physicist. The shape of the bolus was corrected, until the 90% isodose followed the internal border of the PTV. A minimum dose of 85% in some minor regions was considered acceptable. The process of bolus design was usually time-consuming, because the change of the shape in one slice influenced the dose distribution in the neighboring slices. After completion of the bolus design, dose distribution was calculated in a smaller calculation grid size. Photon weight was chosen to have the minimum dose in the supraclavicular region greater than 80%. If it was required to set the weight larger than 110%, then an additional photon beam was added. In the TMS system the weight is described in terms of the energy fluence and therefore the weight of the beam is not affected by blocks. This additional beam was the opposed PA beam to the photon AP beam. Dose distribution, calculated for both photon and electron beams, was normalized to the maximum dose at the central axis of the electron beam. The dose distribution was evaluated by physicists and, if accepted, it was presented to the referring doctor. After acceptance, the dose distribution in the central scan and the protocol were printed for record purpose. Also, the shape of the outer contour of the patient's body in all slices with defined bolus was printed and delivered to mould room staff. The shapes of the photon and electron blocks were sent to the computer block cutter. A typical dose distribution in a plane with both electron and photon fields delivered dose to the PTV is shown in Figure 3 (the plane near the central axis of the electron beam).

Patients were treated with a prescribed dose of 50 Gy with fraction doses of 2 Gy. The dose was prescribed at the maximum dose on the central axis of electron beam.

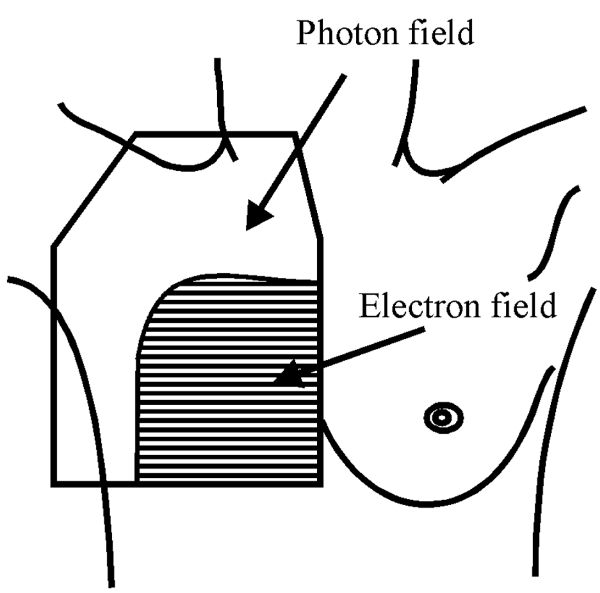

Figure 2. Typical field arrangement of the MIHS technique. For the photon field the dashed region is covered by a block. This region is irradiated by electrons

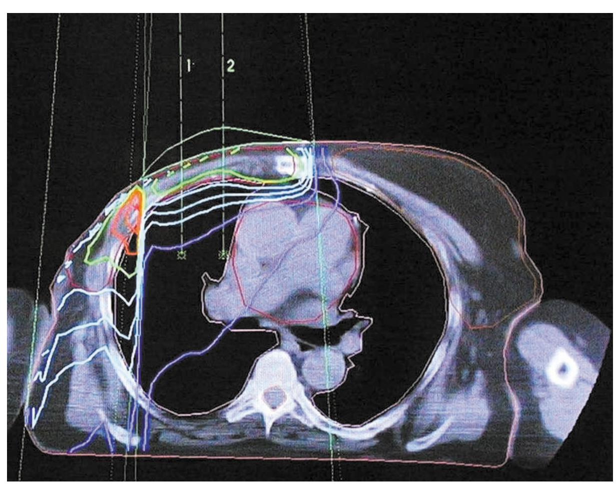

Figure 3. Typical dose distribution for electron and photon beams in the plane near the central axis of the electron beam. The isodose curves of 10%, 50%, 60%, 70%, 80%, 90%, 100% (green one), 110%, 120% values are shown

Figure 4a

Figure 4b

Figure 4. An example of a bolus (left) with its form

Bolus preparation

The bolus was made manually from a mixture of wax and paraffin. It was made of 1 cm thick pieces. Paper shape representing the bolus in each CT slice were attached to every piece of the bolus and then cut off. When all the pieces of the bolus were ready they were joined to each other. Next, the surfaces of the bolus were smoothed. For each bolus a special form made from plaster-bands was prepared. The form protected the bolus from deformation. Whenever the technicians noticed that the bolus had changed shape during the irradiation course, it was placed in its form and put in the heater in approx. 45° C, until the appropriate shape of the bolus was restored. An example bolus with its form is presented in Figure 4.

Treatment simulation and treatment execution

The patient was placed in the treatment position on the treatment simulator. The simulation started with the photon field. The entrance points of the photon fields were obtained by appropriate shifts of the table with respect to the geometrical reference point – G_R. The entrance point was tattooed. After the photon block was placed in the block holder, the shadow of the block edge was marked on the skin with a marker. Along this line a few tattoos were made. Next, the entrance point of the electron beam was defined and the bolus was placed on the skin. The position of the block was carefully defined with respect to the medial edge of the electron field and the outline of the bolus was marked with a marker on the skin. Irradiation was performed in a similar way and the outline contour of the bolus was marked again during every treatment session before irradiation.

Evaluation of dose distribution

For each patient the DVH in the PTV, the lungs and the heart were calculated. In order to compare dose distribution in all patients the dose was normalized to the mean dose to the PTV. For the PTV the standard deviation of the dose was calculated as a measurement of dose homogeneity. The percentage of the PTV volume that received a dose larger than 110% – PTV110 – and less than 90% – PTV90 – were also calculated.

Results

The distribution of electron energies used for the group of 150 patients treated in our hospital in the years 2001 and 2002 is shown in Figure 5.The standard deviation of the

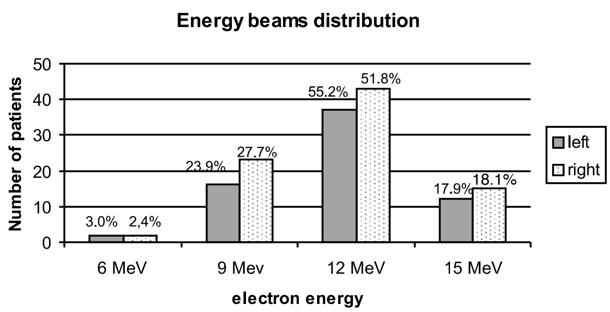

Figure 5. The distribution of the electron beam energies used for MIHS

dose distribution for left sided patients is presented in Figure 6. The LV20 for patients irradiated on the left and right side are shown in Figure 7 and 8, respectively. The H30 for patients irradiated on the left side is shown in Figure 9.

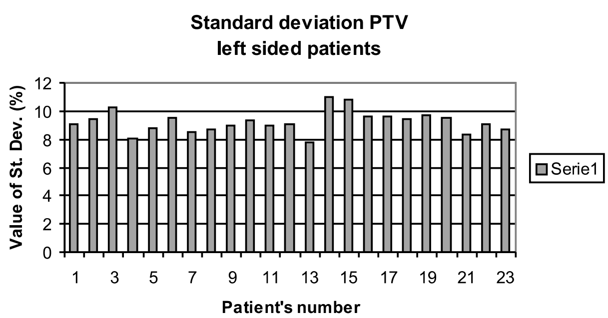

Figure 6. Standard deviation of dose distribution in the PTV

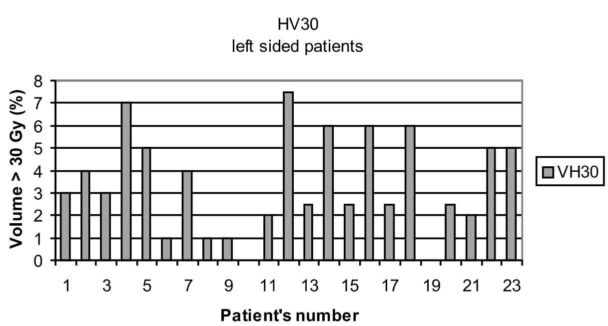

Figure 7. The volume of the heart receiving a dose greater than 30 Gy – data for patients treated to the left side of the chest wall

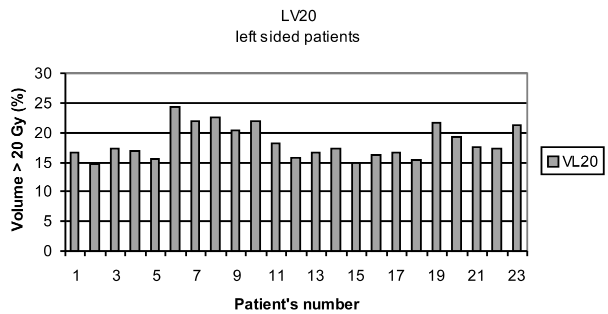

Figure 8. The volume of the lungs receiving a dose greater than 20 Gy – data for patients treated to the left side of the chest wall

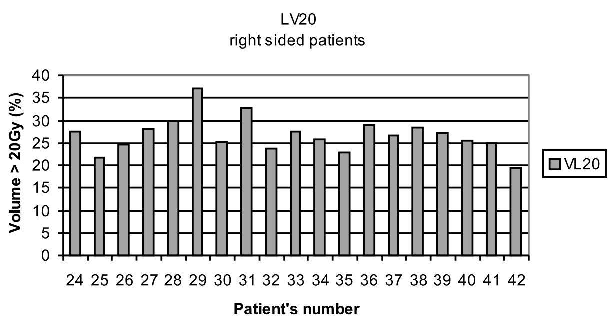

Figure 9. The volume of the lungs that receiving a dose greater than 20 Gy – data for patients treated to the right side of the chest wall

Discussion
– advantages and disadvantages of the HIS technique

Energies of electron beams

The most common energy used for the MIHS technique was 12 MeV. This energy was used in more than 50% of cases on both sides of the chest wall. The average energy used for the right and the left side of the chest wall was 11.7 and 10.0 MeV respectively. The energy of 6 MeV was used very rarely. The 15 MeV energy was used for less than 20% of patients. Application of higher energy was not allowed by our protocol. The technique was changed to standard tangent technique in cases when higher energy had to be used.

Treatment position

The therapeutic position of the patient is a very important feature of the MIHS. The natural body position makes this technique very convenient for the patient. For some patients, even though they received proper physiotherapy, it was difficult to keep the upper limb in this position. Moreover, raising an arm over the head changed the position of the muscles in the axillary and supraclavicular region, resulting in a relatively deeper position of the lymph nodes. On several occasions we attempted to irradiate our patients with arms raised over the head. The aim was to prepare to use the same CT information for the tangential field technique, should the MIHS turn out unacceptable. We noticed that it was never possible to use a single AP photon field to irradiate the lymph nodes in the supraclavicular region, because the minimum dose was always smaller than 80%. For patients lying in this position, additional PA beams had to be applied in the supraclavicular and axillary regions. Our experience shows that in more than 95% cases the MIHS allows irradiation with the AP field only. In most cases the minimal dose delivered to the axillary lymph nodes differed from the prescribed dose by no more than 10%.

Dose distribution in the PTV

All the techniques for post-mastectomy patients were not satisfactory in providing homogenous dose distribution in the target volume [14]. The reasons for not achieving satisfactory coverage of the dose were complicated, involving the large target volume and matching field regions. Also, the application of the electron beam rendered the dose distribution homogeneity worse. For techniques where both the photon and electron beams were used, good matching was impossible to obtain due to a very different penumbra of both fields. The typical penumbra of a photon beam was of about 5 mm, while for the electron beam it was approx. 12 mm. For electron beams the penumbra increased with the depth. In the case of MIHS, the very long matching line (which is usually more than twice as long as that in a standard tangent technique) was an unfavorable factor. As it was shown in Figure 5, the standard deviation for patients irradiated on the left side of the chest wall was about 10%, i.e. far exceeding the acceptable value presented in international standards. Similar results were obtained for patients on the right side of the chest wall. There is no data in the literature to compare with our results. The information about dose homogeneity was limited only to the chest wall region. The only argument indicating that the MIHS technique could be useful despite of the lack of good homogeneity, was the long clinical experience with a similar technique in the Aarhus and the Karolinska.

As it was shown in the histogram of dose distribution in the PTV, the ineffectiveness of matching electron and photon beams appropriately led to deliver doses exceeding the prescribed one by 10% to a subvolume of the PTV. The volume of this region was usually less than 10% of the total volume of the PTV. During 5 years of our experiences with this technique we observed no serious damage to the skin nor to other structures of the chest wall. Early reactions disappeared during a period of 3 to 4 weeks after the completion of the treatment. However, the latent time of fibrosis and appearance teleangiectasia is much longer than 5 years, so the clinical evaluation of this technique with regard to possible consequences of overdosage calls for a longer follow-up period. In all techniques applicable to mastectomy patients beam matching appears to be a problem. Theoretical analysis reveals that the best dose distribution at the match line may be obtained for the monoisocentric standard tangential technique. Unfortunately, that technique can only be performed in linear accelerators with an asymmetric collimator and, also, the match of the treatment beams is only one of a number of parameters that should be taken into account in the choice of treatment technique. Irrespective of the applied technique, a satisfactory repetition should be obtained. In case of a systematic error, the overdosage or underdosage region cannot be avoided. The project realized in the Holycross Cancer Centre was aimed at improving beam matching. About 12% of the PTV volume received a smaller dose than the prescribed one by more than 10%. This volume was mainly situated in the axillary region.

Dose to the radiosensitive organs

The heart and the ipsilateral lung were considered as organs at risk for postmastectomy irradiation. Results of the Stockholm trial have revealed, that the dose delivered to the heart caused an increase in cardiac mortality. Mortality correlated with the volume of the heart that absorbed a dose greater than 30 Gy – HV30. For patients treated on the left side the HV30 was in the 0%-7.5% range with a mean value of 3.5%. This dose was negligible for the heart with respect to the possibility of heart injury. This result proves the technique to be quite safe. The probability of serious heart injury was less than 1%. A smaller dose to the heart was obtained by Pierce in a technique referred to as partially wide tangent fields [14]. However, the definition of PTV used by Pierce differed from ours. In his paper, only the internal mammary nodes located in the first two intercostal spaces were included in the PTV. In our case also the IMN in the third and fourth intercostal spaces were included in the PTV, which definitely increased the dose to the heart.

In the MIHS technique, the dose to the lung depends on the anatomical structure and the energy of the electron beam. The dose to the ipsilateral lung increased in cases with a more curvilinear outline of the electron beam irradiated region and with higher energy electron beams. For the patients irradiated on the left side, the mean value of the LV20 was in the 14.6% and 24.4% range, 18.3% on average. For patients irradiated on the right side the LV20 was in the 23.0% and 32.0% range, 26.7% on average. Based on the data published by Hurkmans, one may estimate that the risk of acute lung pneumonitis for left sided patients as negligible, whereas for right sided patients is does not exceed a few percent. The mean value of the LV20 calculated for the 20 patients treated with a similar technique referred to as the MIHS published by Pierce was 34% [14]. In the MIHS technique the mean LV20 dose was lower than the LV20 dose for the standard tangent, which is characterized by the smallest dose to the lung of all the techniques analyzed by Pierce. In his work on the modified inverse hockey stick technique no individual bolus was used; a smaller dose to the lung can probably be attributed to the application of individual boluses in the MIHS technique. In our case the bolus was shaped to keep the minimum dose at 90%. It may be expected that a smaller dose to the lung could be delivered if the bolus was designed tracing along the 80% isodose, but then the dose distribution homogeneity would be inferior. The possibility to choose the match line between the electron and photon beam individually is another advantage of the MIHS. For slimmer patients this border was moved up in order to diminish the dose to the upper lobe of the lung from the AP photon beam. The possibility to change this border was very limited for the most common techniques such as the tangential field techniques.

Technical aspects of the MIHS

The MIHS may be used only with CT based data, which provides precise information regarding the thickness of the chest wall. It is not possible to design an appropriate individual bolus without such information. The use of a standard bolus may cause excessive irradiation of the lung and deliver too small a dose at least to parts of the PTV. Therefore, in the authors' opinion, the MIHS should be based on 3D CT treatment planning. Treatment planning for the MIHS technique is very time-consuming and may be performed only by a highly experienced specialist. Also, the bolus design is a challenge for the team of the mould room. The average time of MIHS preparation was about 6-8 hours, about 2 to 3 times more than for the standard tangential technique. On the other hand the realization of the MIHS technique at the linear accelerator is relatively easy. The only problem was placing a very heavy photon block in the block holder. This disadvantage can be partly overcome by diminishing the photon block by means of applying the multileaf collimator.

Conclusions

1. The main advantages of the Modified Inverse Hockey Stick technique are: a very convenient and reproducible position of the patient, allowing 3D treatment planning in the whole PTV and a small dose to the organs at risk – to the ipsilateral lung and heart.
2. The individual bolus plays an important role in diminishing the dose to the lung and to the heart.
3. The disadvantages of this technique are poor dose homogeneity in the target volume and a long matching line of electron and photon beams.
4. The MIHS is very time consuming at the preparation stage and very convenient at irradiation.

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