Conceptus Dose from Involved-Field Radiotherapy for Hodgkin's Lymphoma on a Linear Accelerator Equipped with MLCs

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Purpose: To estimate the scattered dose to conceptus from involved-field radiotherapy for Hodgkin's lymphoma on a linear accelerator equipped with multileaf collimators.
Material and Methods: Anthropomorphic phantoms were used to simulate an average pregnant woman at the 1st, 2nd and 3rd trimesters of gestation. Conceptus dose was measured using thermoluminescent dosimeters. Phantom measurements were performed for the minimum, medium and maximum field dimensions that may be employed during radiation therapy to lymph nodes in the neck, axilla, mediastinum and neck-mediastinum. The components of the scattered dose to conceptus were determined. Phantom exposures were generated with a 6-MV photon beam.
Results: Neck irradiation with a tumor dose of 35 Gy resulted in a conceptus dose of 1.1–8.7 cGy depending upon the stage of pregnancy, the distance from treatment volume, and the field size applied. The corresponding conceptus dose ranges from radiotherapy in the regions of axilla, mediastinum and neck-mediastinum was 1.2–14.3 cGy, 3.7–57.7 cGy, and 5.1–91.8 cGy, respectively. The contribution of collimator scatter and head leakage to the total conceptus dose varied from 21% to 80% depending upon the irradiation site and gestational age.
Conclusion: The conceptus dose associated with cervical node irradiation is below the threshold value of 10 cGy during the entire pregnancy. Radiation therapy to lymph nodes in the axilla, mediastinum and neck-mediastinum may possibly lead to a conceptus dose of > 10 cGy and, therefore, informed decisions about the pregnancy termination should be made.

Key Words: Conceptus dose · Hodgkin's lymphoma · Radiotherapy

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Die Strahlendosis im Fetus von Involved-Field-Radiotherapie wegen Hodgkin-Lymphom an einem Linearbeschleuniger mit Multileafkollimatoren (MLC)

Ziel: Messung der durch Streustrahlung bedingten fetalen Dosis bei Involved-Field-Radiotherapie wegen Hodgkin-Lymphom an einem Linearbeschleuniger mit Multileafkollimatoren (MLC).
Material und Methodik: An anthropomorphen Phantomen wurde eine durchschnittliche Schwangere im 1., 2. und 3. Trimenon simuliert. Die Dosis im Fetus wurde mit Thermolumineszenzdosimetern gemessen. Die Phantommessungen wurden für die minimalen, mittleren und maximalen Feldgrößen durchgeführt, die bei der Bestrahlung von Lymphknoten in Hals, Axilla, Mediastinum und Hals-Mediastinum verwendet werden können. Der Anteil der Streustrahlendosis im Fetus wurde bestimmt. Die Phantomexposition wurde mit 6-MV-Photonenstrahlung generiert.
Ergebnisse: Die Bestrahlung des Halses mit einer Tumordosis von 35 Gy führte in Abhängigkeit von Schwangerschaftsstadium, Entfernung vom Behandlungsvolumen und verwendeter Feldgröße zu einer fetalen Dosis von 1,1–8,7 cGy. Die entsprechenden fetalen Dosisbereiche bei Bestrahlung in der Axilla-, Mediastinum- und Hals-Mediastinum-Region betrugen 1,2–14,3 cGy, 3,7–57,7 cGy und 5,1–91,8 cGy. Der Anteil von Kollimatorstreuung und Kopfleckage an der Gesamtdosis, welcher der Fetus ausgesetzt ist, liegt in Abhängigkeit von Tumorsitz und Gestationsalter bei 21–80%.
Schlussfolgerung: Die fetale Dosis bei Bestrahlung der zervikalen Lymphknoten liegt während der gesamten Schwangerschaft < 10 cGy. Die Bestrahlung von Lymphknoten in Axilla, Mediastinum und Hals-Mediastinum führt möglicherweise zu einer fetalen Dosis > 10 cGy, so dass nach Aufklärung eine Entscheidung hinsichtlich eines Schwangerschaftsabbruchs getroffen werden sollte.

Schlüsselwörter: Strahlendosis im Fetus · Hodgkin-Lymphom · Strahlentherapie

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Introduction

Lymphoma is the fourth most common malignancy occurring in pregnant women [9]. The incidence rate of Hodgkin's disease ranges from 1 in 1,000 to 1 in 6,000 pregnancies [23]. Radiotherapy has been effectively employed for the management of Hodgkin's lymphoma during pregnancy [12]. However, in utero irradiation can present major risks to the developing fetus. Conceptus dose estimation prior to radiation therapy is required to balance patient benefit and conceptus risk.

Conceptus dose measurements from extended- or involved-field radiotherapy for Hodgkin's lymphoma at different periods of pregnancy have been reported in the literature [1, 3–5, 11, 17, 21, 22, 27, 28, 30]. All the above dosimetric data were obtained on therapy machines without multileaf collimators (MLCs). The required shielding of healthy tissues lying inside the primary radiation field was performed with the aid of custom cerrobend blocks attached to a tray and mounted to the gantry head. Sherazi & Kase [25] have reported that the use of blocked fields can increase the out-of-field dose compared with that from open portals due to the additional scattered radiation emanating by both the blocks and tray. Field shaping is recommended to be performed with MLCs instead of conventional blocks whenever there is a special consideration for the out-of-field dose to critical structures [18]. Greskovich & Macklis [8] have suggested that the use of blocks for field shaping should be minimized or even eliminated during radiotherapy of pregnant women. To our knowledge, there are no data available about the conceptus dose resulting from radiotherapy for Hodgkin's disease on linear accelerators with MLCs.

Several studies have provided out-of-field dose distributions from MLC therapy machines using direct measurements [19, 20, 24, 26, 29] or Monte Carlo calculations [15]. Scattered dose values were obtained on water or solid phantoms using open radiation fields with square or rectangular dimensions. The aforementioned methodology could not address the clinical situation associated with radiotherapy of Hodgkin's disease during pregnancy taking the inability of the phantom arrangements to simulate the real abdominal size at different gestational ages and the irregularly shaped fields currently employed for lymph node irradiation into account.

The objective of the current study was to estimate the scattered dose received by the conceptus from involved-field radiotherapy for Hodgkin's lymphoma on a linear accelerator equipped with MLCs using anthropomorphic phantoms simulating a pregnant woman at the 1st, 2nd and 3rd trimesters of gestation.

Material and Methods

Pregnancy Simulation

The geometry of a pregnant woman was simulated by means of a Rando anthropomorphic phantom made of tissue-equivalent material (Alderson Research Labs, Stanford, CA, USA). The phantom consists of 36 numbered 2.5 cm thick transverse slices and it represents a body trunk of an adult 1.73 m in height and 73.5 kg in weight. The phantom can simulate pregnancy at the first postconception weeks since the dimensions of abdomen are not changed significantly by the growing conceptus during this period. The Rando phantom was modified by replacing slices 25–31 with seven Lucite sections representing the abdominal region of a pregnant woman at the 2nd trimester of gestation [16]. Ten Lucite sections replaced Rando slices 22–31 to simulate pregnancy at the 3rd trimester [16]. The thickness of Lucite sections was 2.5 cm and they contained a hole grid allowing the accommodation of thermoluminescent dosimeters (TLDs).

Irradiation Techniques

Conceptus dose measurements were not carried out for subdiaphragmatic radiotherapy that may expose the conceptus to primary radiation making the preservation of fetal life impossible. Radiotherapy for Hodgkin's disease during pregnancy is limited to lymph node areas above the diaphragm. The field sizes employed nowadays during involved-field [6, 13] or involved-node radiotherapy [7] have been considerably decreased. Supradiaphragmatic irradiation is usually performed in the lymphoid regions of neck, axilla, mediastinum and neck-mediastinum [13]. Phantom exposures were generated with a 6-MV photon beam (Primus, Siemens, Erlangen, Germany).

Computed tomography (CT) scanning of the neck and thorax of the Rando phantom was generated on a Somatom Sensation 16 system (Siemens, Forchheim, Germany). CT images were transferred to a radiotherapy planning system (XiO 4.3.1, CMS, Saint Louis, MO, USA). All radiation fields were planned by a radiotherapist experienced in the management of hematologic malignancies in collaboration with a medical physicist. Treatment plan verification was performed on the simulator (SIMVIEW NT, Siemens, Erlangen, Germany) of our department. A two-field technique consisting of equally weighted anteroposterior (AP) and posteroanterior (PA) portals was used for radiotherapy in all lymphoid regions. For each treatment site, three different field sizes corresponding to the minimum, medium and maximum field dimensions that may be applied in everyday clinical practice were designed (Table 1). MLCs were employed to protect healthy tissues located inside the irradiated area. The lung apex and humeral head were shielded during radiotherapy in the neck and axilla, respectively. Treatment of mediastinal Hodgkin's disease with or without involvement of cervical nodes was made by shielding the lungs.

Conceptus Dose Measurements

Conceptus dose measurements were carried out using calcium fluoride TLDs (TLD-200, Harshaw, Solon, OH, USA) because of their high sensitivity. The crystals were read using a Harshaw 3500 reader. The annealing process consisted of heating the TLDs at 320 °C for 10 min. The crystals were

Table 1. Distances (in cm) between phantom sections and the lower field edge for radiotherapy in the regions of neck, axilla, mediastinum and neck-mediastinum with the minimum, medium and maximum field sizes.

Tabelle 1. Entfernungen (in cm) zwischen Phantomschnitten und unterem Feldrand für die Strahlentherapie in den Hals-, Axilla-, Mediastinum- und Hals-Mediastinum-Regionen mit den minimalen, mittleren und maximalen Feldgrößen.

Irradiation site	Field size (cm^2)	Phantom section #					
		22	25	27	28	30	31
Neck	10.0 × 15.6	27.45	34.95	39.95	42.45	47.45	49.95
	12.0 × 18.3	26.10	33.60	38.60	41.10	46.10	48.60
	14.5 × 20.5	25.00	32.50	37.50	40.00	45.00	47.50
Axilla	9.0 × 11.4	14.65	22.15	27.15	29.65	34.65	37.15
	11.2 × 13.4	13.65	21.15	26.15	28.65	33.65	36.15
	13.7 × 15.6	12.55	20.05	25.05	27.55	32.55	35.05
Mediastinum	10.9 × 17.4	10.25	17.75	22.75	25.25	30.25	32.75
	11.9 × 19.4	9.25	16.75	21.75	24.25	29.25	31.75
	13.0 × 21.4	8.25	15.75	20.75	23.25	28.25	30.75
Neck-mediastinum	21.8 × 27.7	10.25	17.75	22.75	25.25	30.25	32.75
	24.4 × 30.1	9.05	16.55	21.55	24.05	29.05	31.55
	27.1 × 33.0	7.60	15.10	20.10	22.60	27.60	30.10

Table 2. Conceptus dose from radiotherapy for Hodgkin's lymphoma at the 1st trimester of gestation. AP: anteroposterior; PA: posteroanterior.

Tabelle 2. Fetale Dosis bei Strahlentherapie wegen Hodgkin-Lymphom im 1. Trimenon der Schwangerschaft. AP: anteroposterior; PA: posteroanterior.

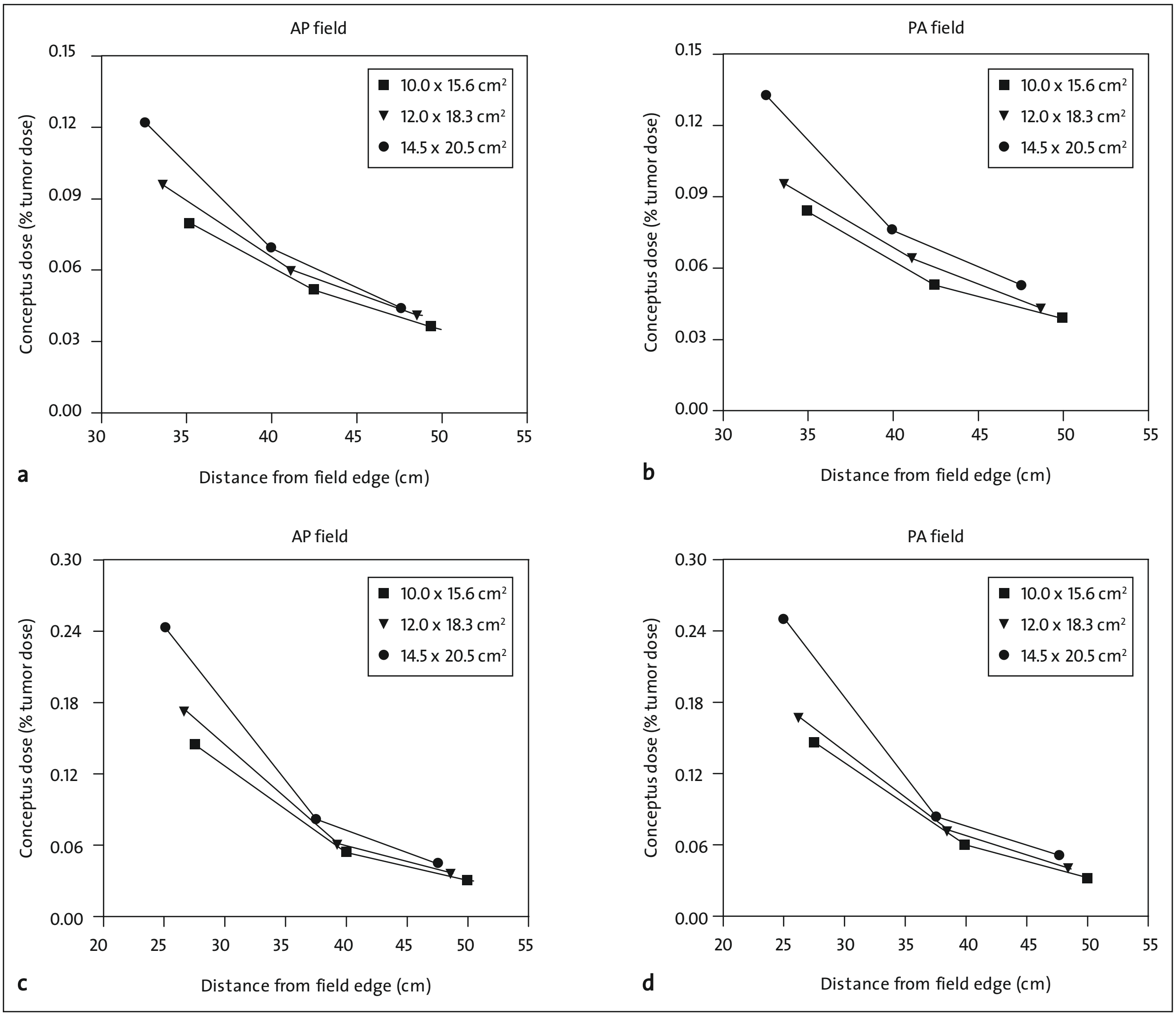
Irradiation site	Field size (cm^2)	Conceptus dose (% tumor dose)	
		AP	PA
Neck	10.0 × 15.6	0.046	0.048
	12.0 × 18.3	0.055	0.054
	14.5 × 20.5	0.068	0.081
Axilla	9.0 × 11.4	0.048	0.050
	11.2 × 13.4	0.050	0.056
	13.7 × 15.6	0.082	0.091
Mediastinum	10.9 × 17.4	0.14	0.12
	11.9 × 19.4	0.16	0.14
	13.0 × 21.4	0.21	0.21
Neck-mediastinum	21.8 × 27.7	0.19	0.20
	24.4 × 30.1	0.26	0.23
	27.1 × 33.0	0.31	0.36

calibrated in comparison with a 0.3-cm^3 thimble ionization chamber (M31003, PTW, Freiburg, Germany) with 6-MV X-rays produced by the same linear accelerator as that used for conceptus dose estimation. The crystals were aggregated into groups according to their sensitivity. The inherent variability of TLD sensitivity was < 3% for each group. The background signal was measured and subtracted from the TLD signal in all measurements.

For the 1st trimester of gestation, measurements were carried out at a single section taking the small embryo size into account. Five TLD crystals were loaded in the Rando phantom section 30 to estimate conceptus dose. Dose measurements at advanced gestational ages were made at three different levels corresponding to the fundus, symphysis pubis and umbilicus or midpoint [27]. The upper, middle and lower conceptus levels at the 2nd trimester of gestation were located in Lucite sections 25, 28, and 31, respectively. The corresponding levels at the 3rd trimester of gestation were in Lucite sections 22, 27, and 31, respectively. Seven, nine and seven TLDs were used to estimate the radiation dose at the upper, middle and lower conceptus levels. One TLD was positioned in each hole inside the phantom at all gestational ages. The average value of the TLD readings in each section was calculated and taken as the conceptus dose at this level. The crystals placed in each section were distributed over the fetal area to detect all possible dose differences within the conceptus. The distances separating the sections 22, 25, 27, 28, 30, and 31 from the beam edge for all field sizes are given in Table 1. To obtain significant TLD readings, phantom exposures were designed to deliver a prescribed tumor dose of 1,000 cGy per field. The total conceptus dose was calculated for a tumor dose of 35 Gy which may be given during radiotherapy for Hodgkin's disease [14].

Conceptus Dose Components

Additional measurements were performed to estimate the components of conceptus dose. The first component was associated with radiation emanating outside the phantom's body (D_{ex}) and it included the scatter from collimating structures and head leakage. The second component came from the scatter arising within the treatment volume of the phantom (D_{in}). All irradiations of the humanoid phantoms were made using the same setup as that described in previous sections. The TLDs were placed into Rando phantom or Lucite slices at the same positions as occupied during total conceptus dose estimation. The only difference was that the slices constituting the treatment volume were removed from the phantom. Therefore, the primary beam was directed just outside the phantom's body and no interactions between photons and phantom material took place. The obtained TLD measurements gave an estimation of D_{ex}. The difference between the total conceptus dose and D_{ex} provided the D_{in}. For each irradiation site, phantom exposures were performed using the medium field size at the three different gestational ages.



Figures 1a to 1d. Conceptus dose from radiotherapy in the neck region with anteroposterior (AP) and posteroanterior (PA) fields at the 2nd (a, b) and 3rd (c, d) trimesters of gestation.

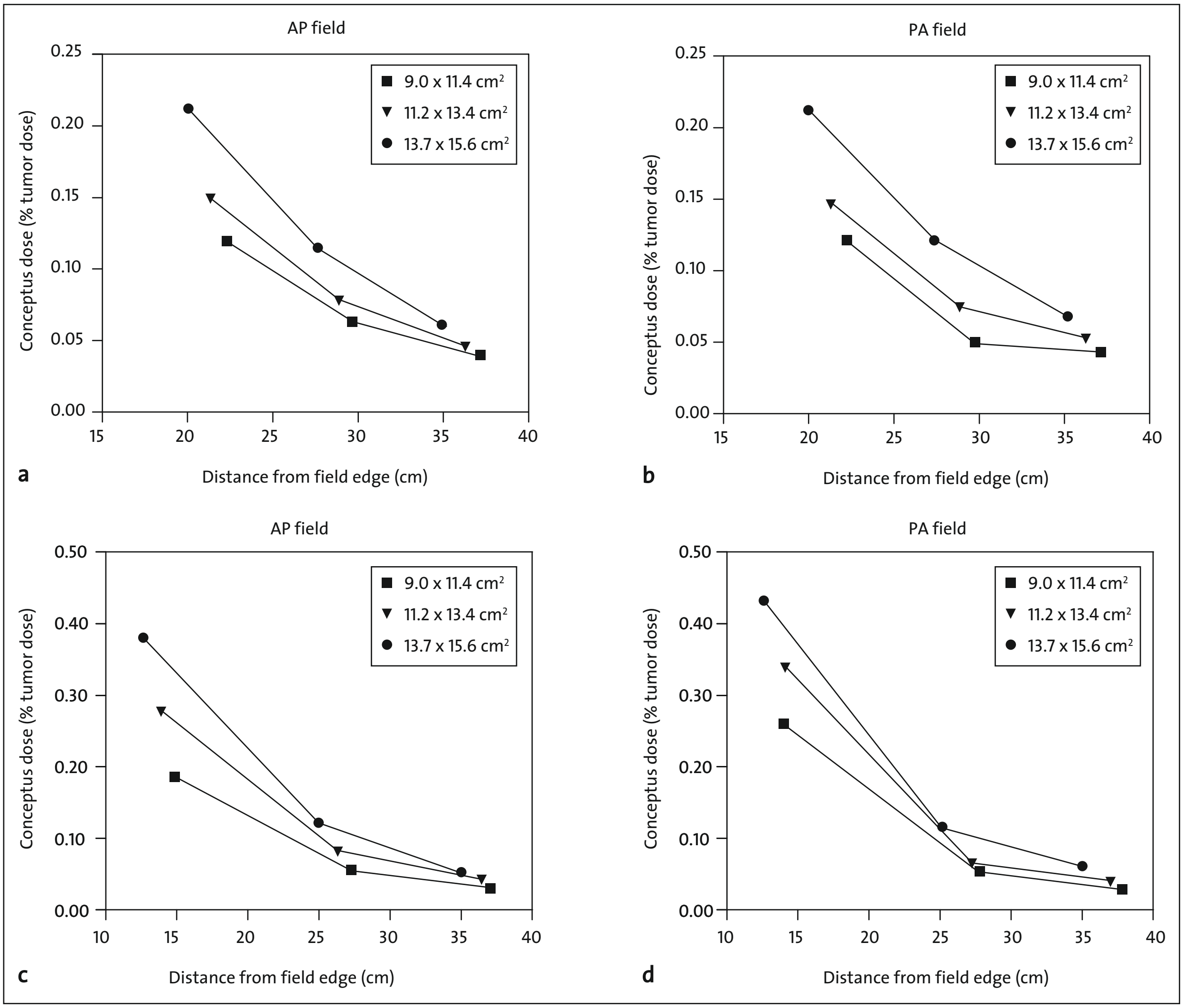
Abbildungen 1a bis 1d. Fetale Dosis bei Strahlentherapie in der Halsregion mit anteroposterioren (AP) und posteroanterioren (PA) Feldern im 2. (a, b) und 3. (c, d) Trimenon der Schwangerschaft.

Results

The conceptus dose from AP and PA field irradiations in the regions of neck, axilla, mediastinum and neck-mediastinum at the 1st trimester of gestation is presented in Table 2. For advanced gestational ages, dose measurements at the upper, middle and lower conceptus levels from treatment of supradiaphragmatic Hodgkin's disease are shown in Figures 1 to 4. Conceptus dose increased with the increase in field size and the reduction of the distance from the irradiated area.

The total radiation dose to conceptus for a treatment course delivering 35 Gy to the tumor is presented in Table 3. For gestational ages up to 12 weeks, conceptus dose from irradiation in the neck, axilla, mediastinum and neck-mediastinum was 1.6–2.6 cGy, 1.7–3.0 cGy, 4.9–7.4 cGy, and 6.8–11.7 cGy, respectively, depending upon the field dimensions used. Pregnancy progression resulted in a considerable conceptus dose increase. Radiotherapy to lymph nodes in the neck, axilla, mediastinum and neck-mediastinum at the 2nd trimester of gestation resulted in a total scattered dose of 1.3–4.5 cGy, 1.4–7.4 cGy, 3.6–23.2 cGy, and 5.6–34.4 cGy, respectively. The corresponding dose ranges at the 3rd trimester of gestation were 1.1–8.7 cGy, 1.2–14.3 cGy, 3.7–57.7 cGy, and 5.1–91.8 cGy, respectively.

The contribution of D_{ex} and D_{in} to the total conceptus dose from radiotherapy for Hodgkin's disease is presented in Table 4. For cervical node irradiation, D_{ex} accounted for



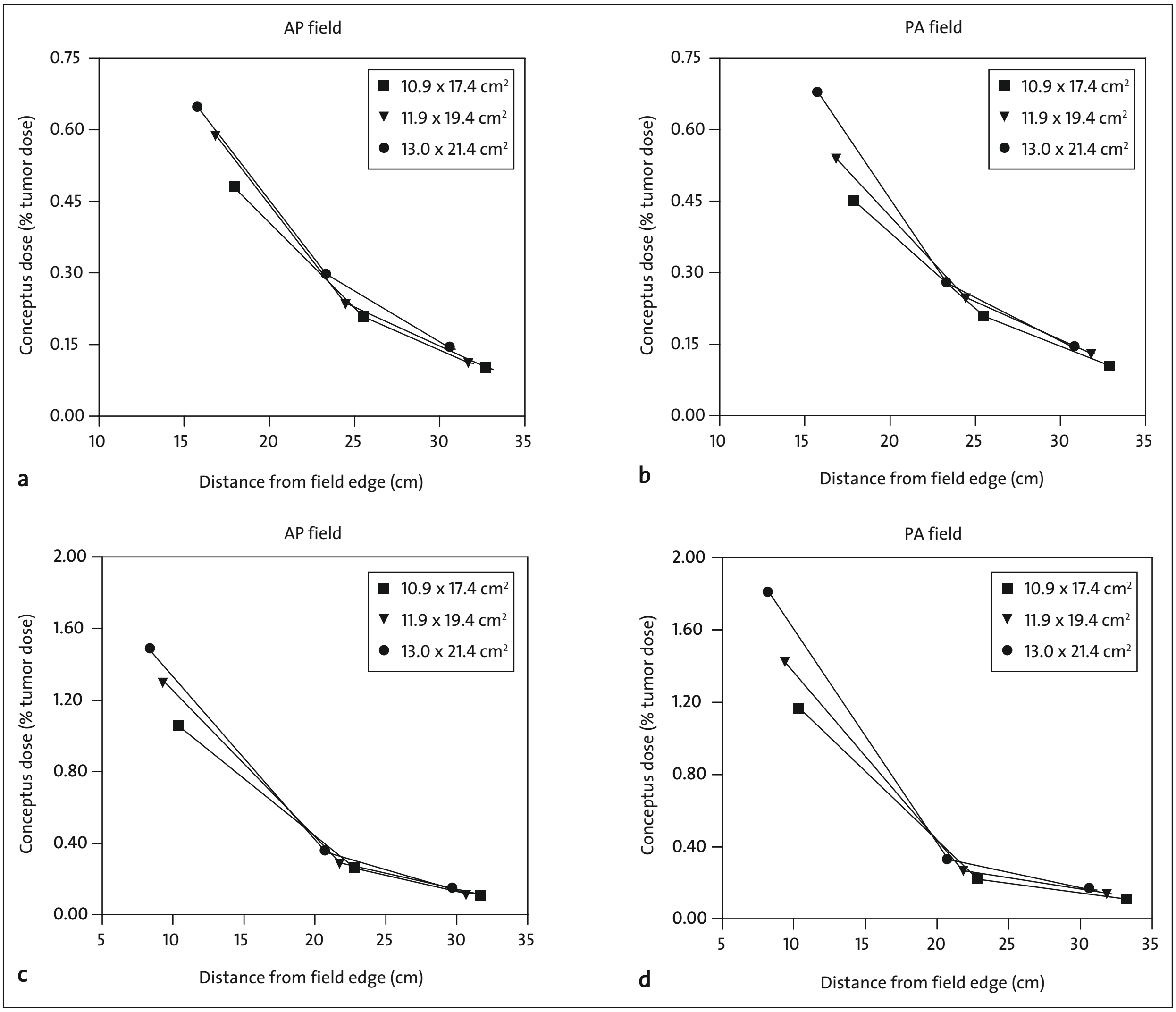
Figures 2a to 2d. Conceptus dose from radiotherapy in the axillary region with anteroposterior (AP) and posteroanterior (PA) fields at the 2nd (a, b) and 3rd (c, d) trimesters of gestation.

Abbildungen 2a bis 2d. Fetale Dosis bei Strahlentherapie in der Axillaregion mit (AP) anteroposterioren und posteroanterioren (PA) Feldern im 2. (a, b) und 3. (c, d) Trimenon der Schwangerschaft.

58–80% of the total conceptus dose depending upon the gestational age and the distance separating the treatment field from the measurement level within the conceptus. The corresponding contribution from radiotherapy in the regions of axilla, mediastinum and neck-mediastinum was 39–79%, 21–60%, and 29–53%, respectively.

Discussion

The International Commission of Radiological Protection (ICRP) has suggested that pregnancy termination is not justified at conceptus doses of < 10 cGy [10]. Conceptus dose > 10–20 cGy may cause deterministic effects including fetal death, central nervous system abnormalities, malformations, and growth retardation [10]. Simulated phantom measurements revealed that the conceptus dose from cervical node irradiation is below the threshold of 10 cGy at all gestational ages, irrespective of the irradiated area and the distance from the inferior field edge. The radiation dose to conceptus from treatment in the axilla exceeded the threshold value at the upper fetal level only when treatment was performed with the medium or the maximum field sizes at the 3rd trimester of gestation. Radiotherapy for mediastinal Hodgkin's disease at the 2nd and 3rd trimesters of gestation resulted in a conceptus dose of > 10 cGy at the upper fetal level for all field dimensions and at the middle fetal level for the maximum field size. For middle and late pregnancy, the conceptus dose from

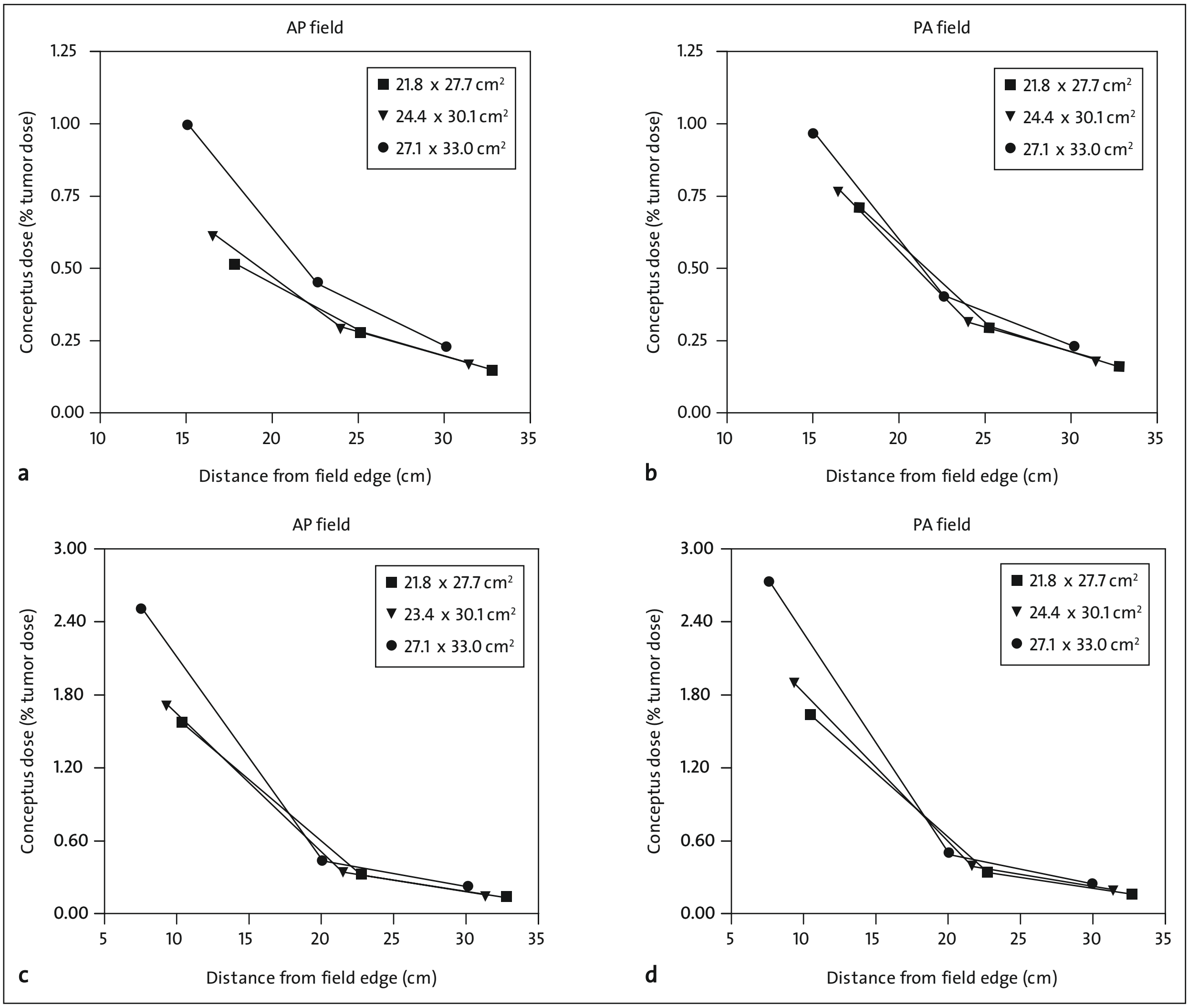


Figures 3a to 3d. Conceptus dose from radiotherapy in the region of mediastinum with anteroposterior (AP) and posteroanterior (PA) fields at the 2nd (a, b) and 3rd (c, d) trimesters of gestation.

Abbildungen 3a bis 3d. Fetale Dosis bei Strahlentherapie in der Mediastinumregion mit anteroposterioren (AP) und posteroanterioren (PA) Feldern im 2. (a, b) und 3. (c, d) Trimenon der Schwangerschaft.

irradiation in the lymphoid region of neck-mediastinum exceeded the well tolerated dose at the upper and middle fetal levels, irrespective of the applied treatment field dimensions. Moreover, radiotherapy to the neck-mediastinum with the maximum field size during the first postconception weeks led to a conceptus dose > 10 cGy.

Shielding material consisting of four to five half-value layers of lead on a portable device is usually placed over patient's abdomen to reduce conceptus dose [5, 16, 17, 27, 30]. Buchgeister et al. [2] have recommended a more sophisticated approach where a tunnel made of lead is placed over the abdominopelvic region of the pregnant woman. A question arising is whether the implementation of shielding material during lymph node irradiation can provide conceptus doses below the threshold value of 10 cGy. Lead shielding can protect the conceptus from D_{ex} while it has no effect on D_{in}. The magnitude of D_{in} is the main factor determining whether the total conceptus dose may be reduced below the threshold introduced by the ICRP. For radiotherapy to lymph nodes in the axillary region with the medium field size at late pregnancy, the use of adequate shielding material can lead to a total conceptus dose below the well-established threshold since D_{in} is much smaller than 10 cGy. Conceptus dose from radiotherapy to mediastinum and/or neck-mediastinum at the 2nd and 3rd trimesters of gestation will exceed the value of 10 cGy at the upper fetal level even if shielding equipment is applied. However, on the



Figures 4a to 4d. Conceptus dose from radiotherapy in the region of neck-mediastinum with anteroposterior (AP) and posteroanterior (PA) fields at the 2nd (a, b) and 3rd (c, d) trimesters of gestation.

Abbildungen 4a bis 4d. Fetale Dosis bei Strahlentherapie in der Hals-Mediastinum-Region mit anteroposterioren (AP) und posteroanterioren (PA) Feldern im 2. (a, b) und 3. (c, d) Trimenon der Schwangerschaft.

basis of the concept that all diagnostic and therapeutic exposures of pregnant women to ionizing radiation should always be tailored to reduce conceptus dose [10], shielding material can be employed whenever available and possible.

The dosimetric results of this study can be used for conceptus dose prediction prior to radiotherapy for Hodgkin's lymphoma. Determination of fetal location by means of an ultrasound examination is required to find the distance between conceptus and field edge. Accurate knowledge of the above distance allows radiotherapists and medical physicists to use the presented tabular and graphic data and obtain reasonable conceptus dose predictions taking the effects of field size and gestational age into account. Sources of error in conceptus dose prediction are related to the uncertainty in TLD dosimetry. Moreover, the assumptions made about conceptus size and position and the variations of the phantoms' geometry and size from those of real patients can lead to unknown uncertainties. It should be noted that all humanoid phantoms' irradiations were performed without the introduction of wedges into the primary beam. The above practice is usually adopted during radiotherapy of pregnant women in order to reduce conceptus dose [8]. Reported experience has suggested that the use of wedges can increase the radiation dose outside the treatment field by a factor of 2–4 [25].

The comparison of the presented conceptus dose values with those previously reported [1, 3–5, 11, 21, 22, 27, 28, 30]

Table 3. Total conceptus dose from involved-field radiotherapy for Hodgkin's lymphoma. Dose values correspond to a tumor dose of 35 Gy.

Tabelle 3. Fetale Gesamtdosis bei Involved-Field-Strahlentherapie wegen Hodgkin-Lymphom. Die Dosiswerte entsprechen einer Tumordosis von 35 Gy.

Irradiation site	Field size (cm²)	Conceptus dose (cGy)						
		1st trimester	2nd trimester			3rd trimester		
			Upper level	Middle level	Lower level	Upper level	Middle level	Lower level
Neck	10.0 × 15.6	1.6	2.9	1.8	1.3	5.1	2.0	1.1
	12.0 × 18.3	1.9	3.4	2.2	1.5	6.0	2.3	1.3
	14.5 × 20.5	2.6	4.5	2.5	1.7	8.7	2.9	1.7
Axilla	9.0 × 11.4	1.7	4.2	2.0	1.4	7.5	2.1	1.2
	11.2 × 13.4	1.9	5.2	2.7	1.7	10.9	2.8	1.7
	13.7 × 15.6	3.0	7.4	4.1	2.2	14.3	4.1	2.0
Mediastinum	10.9 × 17.4	4.9	16.3	7.4	3.6	39.0	8.4	3.7
	11.9 × 19.4	5.6	19.8	8.6	4.2	48.0	9.8	4.4
	13.0 × 21.4	7.4	23.2	10.2	4.9	57.7	11.9	4.9
Neck-mediastinum	21.8 × 27.7	6.8	21.5	10.2	5.6	56.0	11.6	5.1
	24.4 × 30.1	8.6	24.4	10.7	6.1	63.3	13.0	6.0
	27.1 × 33.0	11.7	34.4	15.0	8.0	91.8	16.3	8.0

Table 4. Contributions of D_{in} and D_{ex} to the total conceptus dose (D_t) from radiotherapy for Hodgkin's lymphoma with the medium field sizes. Dose values correspond to a tumor dose of 35 Gy.

Tabelle 4. Anteil von D_{in} und D_{ex} an der fetalen Gesamtdosis (D_t) bei Strahlentherapie wegen Hodgkin-Lymphom für ein Feld mittlerer Größe. Die Dosiswerte entsprechen einer Tumordosis von 35 Gy.

Irradiation site		Radiation dose (cGy)						
		1st trimester	2nd trimester			3rd trimester		
			Upper level	Middle level	Lower level	Upper level	Middle level	Lower level
Neck	D_t	1.9	3.4	2.2	1.5	6.0	2.3	1.3
	D_{in}	0.5	1.2	0.7	0.3	2.5	0.8	0.3
	D_{ex}	1.4	2.2	1.5	1.2	3.5	1.5	1.0
Axilla	D_t	1.9	5.2	2.7	1.7	10.9	2.8	1.7
	D_{in}	0.4	2.4	0.8	0.4	6.6	1.0	0.5
	D_{ex}	1.5	2.8	1.9	1.3	4.3	1.8	1.2
Mediastinum	D_t	5.6	19.8	8.6	4.2	48.0	9.8	4.4
	D_{in}	2.8	13.7	4.8	1.7	38.0	5.7	2.2
	D_{ex}	2.8	6.1	3.8	2.5	10.0	4.1	2.2
Neck-mediastinum	D_t	8.6	24.4	10.7	6.1	63.3	13.0	6.0
	D_{in}	4.2	16.8	5.9	2.9	44.9	7.2	2.8
	D_{ex}	4.4	7.6	4.8	3.2	18.4	5.8	3.2

is rather difficult due to the wide variety of beam energies employed and the extended fields used. Treatment of nodal disease during pregnancy has been performed with X-rays generated at voltages of < 300 kV [1, 11, 28], a cobalt-60 (^{60}Co) unit [21, 28, 30] and a betatron producing 22.5-MV X-rays [1]. Kilovoltage units and betatrons are no longer used for treatment of lymphadenopathy. Radiotherapy of pregnant women with ^{60}Co beams should be avoided because of the increased head leakage resulting in a high out-of-field dose compared with that from linear accelerators [8, 27]. Several previous studies have reported the use of megavoltage photon beams for mantle irradiation [3, 4, 5, 11, 21, 22, 27, 30]. However, mantle fields are now rarely employed and treatment portals are more restricted in size. Conceptus dose measurements from involved-field radiotherapy on a non-MLC machine have been referred to in the literature [17]. For medium field sizes and distances from the lower field border similar to those used in the current study, the radiation dose to conceptus dose from treatment in the regions of axilla and neck-mediatinum was 3.1 cGy and 16.2 cGy, respectively [17]. The corresponding dose from cervical node irradiation with a single unilateral field was 2.8 cGy [17]. The comparison of the aforementioned dosimetric values with those presented in Table 3 reveals that the conceptus dose from radiotherapy in the regions of neck, axilla and neck-mediastinum can be reduced by 32%, 39%, and 47%, respectively, when the portals are shaped with MLCs instead of custom blocks.

Conclusion

The scattered dose to conceptus from involved-field radiotherapy for Hodgkin's lymphoma on a linear accelerator equipped with MLCs can vary significantly considering many factors including irradiation site, field dimensions and gestational age. Irradiation of cervical lymph nodes always results in a scattered dose of < 10 cGy, whereas the conceptus dose from radiation therapy in the regions of axilla, mediastinum and neck-mediastinum may possibly exceed the above threshold value. Dosimetric data concerning the components of the total conceptus dose may be of value whenever decisions about the construction of special shielding equipment should be made.

References

1. Becker MH, Hyman GA. Management of Hodgkin's disease coexistent with pregnancy. Radiology 1965;85:725–8.
2. Buchgeister M, Mondry A, Spillner P, et al. A special radiation shielding for the radiotherapy of a pregnant patient. Strahlenther Onkol 2008;184:80–5.
3. Conley JG, Jacobson A. Modified radiation therapy regimen for Hodgkin's disease in the third trimester of pregnancy. Am J Radiol 1977;128:666–7.
4. Covington EE, Baker AS. Dosimetry of scattered radiation to the fetus. JAMA 1969;209:414–5.
5. Cygler J, Ding GX, Kendal W, et al. Fetal dose for a patient undergoing mantle field irradiation for Hodgkin's disease. Med Dosim 1997;22:135–7.
6. Eich HT, Muller R. Current role and future developments of radiotherapy in early-stage favorable Hodgkin's lymphoma. Strahlenther Onkol 2007;183:16–8.
7. Eich HT, Muller RP, Engenhart-Cabillic R, et al. Involved-node radiotherapy in early stage Hodgkin's lymphoma. Definition and guidelines of the German Hodgkin Study Group (GHSG). Strahlenther Onkol 2008;184:406–10.
8. Greskovich JF, Macklis RM. Radiation therapy in pregnancy: risk calculation and risk minimization. Semin Oncol 2000;27:633–45.
9. Hass JF. Pregnancy in association with a newly diagnosed cancer: a population-based epidemiologic assessment. Int J Cancer 1984;34:229–35.
10. ICRP. International Commission on Radiological Protection, Publication 84. Pregnancy and medical radiation. Oxford: Pergamon Press, 2000.
11. Jacobs C, Donaldson SS, Rosenberg SA, et al. Management of the pregnant patient with Hodgkin's disease. Ann Intern Med 1981;95:669–75.
12. Kal HB, Struikmans H. Radiotherapy during pregnancy: fact and fiction. Lancet Oncol 2005;6:328–33.
13. Khan FM, ed. Treatment planning in radiation oncology, 2nd edn. Philadelphia: Lippincott Williams & Wilkins, 2007.
14. Koh ES, Tran TH, Heydarian M, et al. A comparison of mantle versus involved-field radiotherapy for Hodgkin's lymphoma: reduction in normal tissue dose and second cancer risk. Radiat Oncol 2007;2:1–11.
15. Kry SF, Titt U, Ponisch F, et al. A Monte Carlo model for calculating out-of-field dose from a Varian 6 MV beam. Med Phys 2006;33:4405–13.
16. Mazonakis M, Damilakis J, Theoharopoulos N, et al. Brain radiotherapy during pregnancy: an analysis of conceptus dose using anthropomorphic phantoms. Br J Radiol 1999;72:274–8.
17. Mazonakis M, Varveris H, Fasoulaki M, et al. Radiotherapy of Hodgkin's disease in early pregnancy: embryo dose measurements. Radiother Oncol 2003;66:333–9.
18. Mazonakis M, Zacharopoulou F, Kachris S, et al. Scattered dose to gonads and associated risks from radiotherapy for common pediatric malignancies. A phantom study. Strahlenther Onkol 2007;183:332–7.
19. Mutic S, Esthappan J, Klein EE. Peripheral dose distributions for a linear accelerator equipped with a secondary multileaf collimator and universal wedge. J Appl Clin Med Phys 2002;3:302–9.
20. Mutic S, Klein EE. A reduction in the AAPM TG-36 reported peripheral dose distributions with tertiary multileaf collimation. Int J Radiat Oncol Biol Phys 1999;44:947–53.
21. Nisce LZ, Tome MA, He S, et al. Management of coexisting Hodgkin's disease and pregnancy. Am J Clin Oncol 1986;9:146–51.
22. Nuytens JJ, Prado KL, Jenrette JM, et al. Fetal dose during radiotherapy: clinical implementation and review of the literature. Cancer Radiother 2002;6:352–7.
23. Pavlidis NA. Coexistence of pregnancy and malignancy. Oncologist 2002;7:279–87.
24. Sharma DS, Animesh, Desphande SS, et al. Peripheral dose from uniform dynamic multileaf collimation fields: implications for sliding window intensity-modulated radiotherapy. Br J Radiol 2006;79:331–5.
25. Sherazi S, Kase KR. Measurements of dose from secondary radiation outside a treatment field: effects of wedges and blocks. Int J Radiat Oncol Biol Phys 1985;11:2171–6.
26. Stern RL. Peripheral dose from a linear accelerator equipped with multileaf collimation. Med Phys 1999;26:559–63.
27. Stovall M, Blackwell CR, Cundiff J, et al. Fetal dose from radiotherapy with photon beams: report of AAPM Radiation Therapy Committee Task Group no. 36. Med Phys 1995;22:63–82.
28. Thomas PRM, Peckham MJ. The investigation and management of Hodgkin's disease in the pregnant patient. Cancer 1976;38:1443–51.
29. Wiezorek T, Voigt A, Metzger N, et al. Experimental determination of peripheral doses for different IMRT techniques delivered by a Siemens linear accelerator. Strahlenther Onkol 2008;184:73–9.
30. Woo SY, Fuller LM, Cundiff JH, et al. Radiotherapy during pregnancy for clinical stages IA–IIA Hodgkin's disease. Int J Radiat Oncol Biol Phys 1992;23:407–12.

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