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Comparative analysis of dose distribution to critical organs in radiation therapy of left breast cancer with respiratory synchronization

Relevance: Breast cancer is one of the most common oncological diseases. Today, it leads among female cancers. Patients with left breast cancer undergoing radiation therapy have a considerable risk of developing cardiovascular diseases caused by ionizing radiation. Various methods are introduced to reduce the radiation load to critical organs to ensure compliance with the main radiation therapy principle. One of these methods is radiation therapy with synchronized breathing, including deep inspiration breath-hold (DIBH). DIBH can significantly reduce the dose load to the heart and the left lung.

The study aimed to compare the radiation load to the heart and the left lung during radiation therapy for left breast cancer with free breathing and respiratory synchronization.

Results: During radiation therapy with synchronized breathing, the average radiation load to the heart is 1.7 times lower and to the left lung – 1.26 times lower compared to radiation therapy with free breathing.

Conclusion: The study results confirm that respiratory synchronization in radiation therapy for left breast cancer reduces the dose to the heart and the left lung.

Keywords: breast cancer, radiation therapy (RT), radiation therapy with respiratory synchronization, deep inspiration breath-hold (DIBH).

Introduction: Breast cancer is one of the most common oncological pathologies. Today, it occupies a leading place among all malignant tumors in women. In the Republic of Kazakhstan, breast cancer ranks third in mortality from malignant neoplasms. In 2018, 4648 people with breast cancer were on record in the Republic of Kazakhstan. The number of breast cancer patients grows every year. From 2014 to 2018, the number of breast cancer cases detected annually has grown from 4142 to 4648, adding 12.2% [1].

Radiation therapy (RT) is an obligatory component of combined or complex treatment of breast cancer. RT is aimed to prevent local (loco-regional) recurrence after surgical treatment. Numerous studies and randomized trials confirm that RT reduces the incidence of local recurrence after breast-conserving surgery and contributes to an increase in the life expectancy of patients [2-4].

Patients with left-sided breast cancer undergoing RT have a significant risk of cardiovascular diseases caused by ionizing radiation.

During 10-15 years of follow-up, it was found that patients who received radiation load to organs at risk during RT had a higher risk of heart and pulmonary diseases compared with those who did not receive RT [5-9]. It was reported that in patients with left-sided breast

or chest wall cancer with latent cardiac toxicity manifesting more than ten years after the initial exposure, there were deaths due to cardiovascular failure [10-11]. In this regard, it is especially necessary to reduce the radiation load to organs at risk in patients with left-sided breast cancer.

RT with respiratory synchronization, including deep-inspiration breath-hold (DIBH), is one of the methods of reducing radiation load to critical organs. DIBH is based on the principle of increasing the spatial separation between the chest wall and heart during inhalation. Several dosimetric studies show that DIBH reduces the radiation load to the heart [12-14].

The study aimed to compare the radiation load to the heart and the left lung during RT for left breast cancer with free breathing and respiratory synchronization.

Materials and Methods: For comparison, the dosimetric plans of RT were used in two patients receiving treatment at the Kazakh Research Institute of Oncology & Radiology. Both patients were diagnosed with left-sided breast cancer with metastases in the lymph nodes. Patients received RT after surgical treatment. RT planning was performed using the Eclipse planning system (Varian Medical Systems, CA, USA). Irradi-

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ation was performed on a Truebeam apparatus (Varian Medical Systems, CA, USA) with a classic fractionation mode of 2 Gy (Gray) per day, 25 fractions (5 weeks), TRD (total radiation dose) – 50 Gy. Patient A. underwent RT using respiratory synchronization systems

(hereinafter – Method 1) (Figure 1). Patient B. underwent RT with free breathing (hereinafter – Method 2) (Figure 2). Maximum and average doses to the heart and left lung were studied. Dose-volume histograms were plotted for analysis.

Figure 1 – Dose distribution for RT with respiratory synchronization

Figure 2 – Dose distribution for RT with free breathing

Results and Discussion:

Tables 3 and 4 show maximum and average doses to critical organs. The following results were obtained for RT with respiratory synchronization: $D_{\max}$ (heart) = 48.196 Gy; $D_{\max}$ (heart) = 5.669 Gy; $D_{\max}$ (left lung) = 51.126 Gy; $D_{\max}$ (left lung) = 12.032 Gy.

In RT with free breathing, the following results

were obtained: $D_{\max}$ (heart) = 50.255 Gy, $D_{\max}$ (heart) = 10.009 Gy, $D_{\max}$ (left lung) = 52.435 Gy, $D_{\max}$ (left lung) = 15.276 Gy.

Hence, in RT with respiratory synchronization, the average doses to the heart and the left lung were 1.7 and 1.26 times less than in RT with free breathing. This difference is shown on the dose-volume histograms (Figures 3, 4).

Table 3 – Numerical data of dose distribution for RT with respiratory synchronization

Structure	Volume (cm ³)	Min. dose (Gy)	Max. dose (Gy)	Av. dose (Gy)
GTV*	19.2	27.106	53.277	48.882
PTV** boost	59.3	2.615	53.277	45.071
Esophagus	4.3	0.594	5.530	3.133
Thyroid	25.9	0.243	1.650	0.671
Total PTV, lymphatic system	172.0	31.047	53.987	48.942
CTV***, axillary lymph nodes 1	33.4	43.704	52.757	48.693
Joint	66.4	1.819	49.651	30.945
Bone tissue, NOS	920.7	0.000	52.914	2.937
CTV, left mammary gland	361.0	4.968	54.120	46.685
CTV, axillary lymph nodes 2	21.7	45.569	52.399	50.213
CTV, axillary lymph nodes 3	7.3	47.467	52.809	51.522
Heart	622.8	0.311	48.196	5.669
Left lung	1762.7	0.239	51.126	12.032
Spine	30.9	0.108	4.600	0.584
Right lung	2295.8	0.000	10.341	0.281
Total CTV, lymphatic system	61.7	43.704	52.809	49.530
Total PTV	648.7	13.791	54.120	47.552
PTV	518.2	13.791	54.120	47.245
Right mammary gland	340.8	0.013	24.025	1.420
Body	15665.3	0.000	54.120	5.485
= "Left lung" or "Right lung"	4058.2	0.000	51.126	5.385

*GTV – gross tumor volume

**PTV – planning target volume

***CTV – clinical target volume

Table 4 – Numerical data of dose distribution for RT with free breathing

Structure	Volume (cm ³)	Min. dose (Gy)	Max. dose (Gy)	Av. dose (Gy)
Body	28428.1	0.000	54.931	4.917
Right mammary gland	437.8	0.024	49.244	1.937
Right lung	1109.8	0.000	18.133	0.790
Spine	74.5	0.026	25.561	2.706
Left lung	912.0	0.261	52.435	15.276
Heart	566.9	0.560	50.255	10.009
CTV*, axillary lymph nodes 3	10.4	47.480	52.927	50.568
CTV, axillary lymph nodes 2	15.0	46.933	53.661	50.753
CTV, left mammary gland	425.7	27.384	54.821	49.079
Bone tissue, NOS	1248.0	0.000	53.626	4.422
Joint	60.1	1.304	49.622	13.484
CTV, axillary lymph nodes 1	55.4	45.907	54.748	50.098
CTV, supraclavicular lymph nodes	17.7	45.808	53.005	50.477
Total PTV**, lymphatic system	282.4	0.000	54.748	49.396
Thyroid	2.4	1.523	52.119	24.022
Trachea	31.2	0.868	48.264	10.283
PTV	925.0	0.000	54.821	39.146
Total PTV	1131.3	0.000	54.821	41.063
Total CTV, lymphatic system	98.5	45.767	54.748	50.313
Total, lungs	2024.1	0.000	52.435	7.318
Larynx	16.0	0.393	2.393	0.958

*CTV – clinical target volume

**PTV – planning target volume

Figure 5 – Dose-volume histogram for RT with synchronization

Figure 6 – Dose-volume histogram for RT with free breathing

Conclusions: An important condition for RT is the irradiation of a malignant tumor and the preservation of the viability of normal tissues and organs. The analysis of the results shows that the use of RT with respiration synchronization makes it possible to reduce the radiation load to critical organs such as the heart and the left lung, which reduces the risk of cardiac and pulmonary post-radiation complications.

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ТҰЖЫРЫМ

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Респираторлық синхрондау жүйелерін қолдана отырып, сол жақ сүт безі қатерлі ісігінің сәулелік терапия кезінде маңызды органдарға дозаның таралуын салыстырмалы талдау

Өзектілігі: Сүт безі қатерлі ісігі ең көп таралған онкологиялық аурулардың бірі болып табылады және бүгінгі күні әйелдердің барлық қатерлі ісіктерінің арасында жетекші орын алады. Сәулелік терапия (СТ) емін алып жатқан, сол жақ сүт безінің қатерлі ісігі бар науқастарда иондаушы сәулеленуден туындаған жүрек-тамыр ауруларының даму қаупі бар. Сәулелік терапияның негізгі принципін сәтті орындау үшін, маңызды органдарға сәулелік жүктемені төмендетудің әртүрлі әдістері енгізілуде. Осындай әдістердің бірі–терең тыныс алу кезінде демді тоқтатып тұруды (deep-inspiration breath-hold, DIBH) қамтитын тыныс алу синхрондауымен сәулелік терапия болып табылады. Бұл әдіс жүрекке және сол жақ өкпеге дозалық жүктемені айтарлықтай азайтуға мүмкіндік береді.

Зерттеудің мақсаты: еркін тыныс алу және тыныс алу циклімен синхрондау жүйесін қолдана отырып, сол жақ сүт безі қатерлі ісігінің сәулелік терапия кезінде жүрекке және сол жақ өкпеге сәулелік жүктемені салыстырмалы талдау.

Нәтижелері: Тыныс алуды синхрондау кезіндегі сәулелік терапия әдісінде, еркін тыныс алу кезіндегі сәулелік терапияға қарағанда жүрекке орташа доза 1,7 есе, ал сол жақ өкпеге 1,26 есе аз түседі.

Қорытынды: Жұмыста алынған нәтижелер, сол жақ сүт безі қатерлі ісігін емдеуде тыныс алуды синхрондау кезіндегі сәулелік терапия әдісін қолдану, жүрек пен өкпеге дозалық жүктемені азайтуға мүмкіндік беретіндігін көрсетті.

Түйінді сөздер: сүт безі қатерлі ісігі, сәулелік терапия, тыныс алу синхрондауымен сәулелік терапия, терең тыныс алған кезде демді тоқтату (deep inspiration breath hold, DIBH).

АННОТАЦИЯ

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Сравнительный анализ дозового распределения на критические органы при лучевой терапии левостороннего рака молочной железы с использованием систем синхронизации дыхания

Актуальность: Рак молочной железы (РМЖ) является одним из самых распространенных онкологических заболеваний и на сегодняшний день занимает лидирующее место у женщин среди всех злокачественных опухолей. Пациенты с левосторонним РМЖ, проходящие лучевую терапию (ЛТ), имеют немалый риск развития сердечно-сосудистых заболеваний, вызванных ионизирующим излучением. Для успешного выполнения главного принципа ЛТ, внедряются различные методы по снижению общей лучевой нагрузки на критические органы. Одним из таких методов является ЛТ с синхронизацией дыхания, включая задержку дыхания на глубоком вдохе (deep-inspiration breath-hold, DIBH). Данный метод позволяет существенно снизить дозовую нагрузку на сердце и левое легкое.

Цель исследования: проведение сравнительного анализа лучевой нагрузки на сердце и левое легкое при лучевой терапии левостороннего РМЖ при свободном дыхании и с применением системы синхронизации с дыхательным циклом.

Результаты: В методе ЛТ с синхронизацией дыхания по сравнению с ЛТ при свободном дыхании средняя лучевая нагрузка на сердце снижается в 1,7 раза, а средняя доза на левое легкое – в 1,26 раза.

Заключение: Результаты исследования показывают, что использование систем синхронизации дыхания при лучевой терапии левостороннего РМЖ снижает дозовую нагрузку на сердце и левое легкое.

Ключевые слова: рак молочной железы (РМЖ), лучевая терапия (ЛТ), лучевая терапия с синхронизацией дыхания, задержка дыхания на глубоком вдохе (deep-inspiration breath-hold, DIBH).