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ЕЖЕМЕСЯЧНЫЙ НАУЧНЫЙ ЖУРНАЛ

Медицинские новости Грузии
საქართველოს სამედიცინო სიახლეები

GEORGIAN MEDICAL NEWS

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GMN: Georgian Medical News is peer-reviewed, published monthly journal committed to promoting the science and art of medicine and the betterment of public health, published by the GMN Editorial Board since 1994. GMN carries original scientific articles on medicine, biology and pharmacy, which are of experimental, theoretical and practical character; publishes original research, reviews, commentaries, editorials, essays, medical news, and correspondence in English and Russian.

GMN is indexed in MEDLINE, SCOPUS, PubMed and VINITI Russian Academy of Sciences. The full text content is available through EBSCO databases.

GMN: Медицинские новости Грузии - ежемесячный рецензируемый научный журнал, издаётся Редакционной коллегией с 1994 года на русском и английском языках в целях поддержки медицинской науки и улучшения здравоохранения. В журнале публикуются оригинальные научные статьи в области медицины, биологии и фармации, статьи обзорного характера, научные сообщения, новости медицины и здравоохранения. Журнал индексируется в MEDLINE, отражён в базе данных SCOPUS, PubMed и ВИНИТИ РАН. Полнотекстовые статьи журнала доступны через БД EBSCO.

GMN: Georgian Medical News – საქართველოს სამედიცინო ხიახლები – არის უფლებული სამეცნიერო სამედიცინო რევიუზირებადი ჟურნალი, გამოიცემა 1994 წლიდან, წარმოადგენს სარედაქციო კოლეგიისა და აშშ-ის მეცნიერების, განათლების, ინდუსტრიის, ხელოვნებისა და ბუნებისმეცნიელების საერთაშორისო აკადემიის ერთობლივ გამოცემას. GMN-ში რეცენზირდება ინგლისურ ენებზე ქვეყნება ექსპერიმენტული, თეორიული და პრაქტიკული ხასიათის ორიგინალური სამეცნიერო სტატიები მედიცინის, ბიოლოგიისა და ფარმაციის სფეროში, მიმოხილვითი ხასიათის სტატიები.

ჟურნალი ინდექსირებულია MEDLINE-ის საერთაშორისო სისტემაში, ასახულია SCOPUS-ის, PubMed-ის და ВИНИТИ РАН-ის მონაცემთა ბაზებში. სტატიების სრული ტექსტი ხელმისაწვდომია EBSCO-ს მონაცემთა ბაზებიდან.

WEBSITE

www.geomednews.com

К СВЕДЕНИЮ АВТОРОВ!

При направлении статьи в редакцию необходимо соблюдать следующие правила:

1. Статья должна быть представлена в двух экземплярах, на русском или английском языках, напечатанная через **полтора интервала на одной стороне стандартного листа с шириной левого поля в три сантиметра**. Используемый компьютерный шрифт для текста на русском и английском языках - **Times New Roman (Кириллица)**, для текста на грузинском языке следует использовать **AcadNusx**. Размер шрифта - **12**. К рукописи, напечатанной на компьютере, должен быть приложен CD со статьей.

2. Размер статьи должен быть не менее десяти и не более двадцати страниц машинописи, включая указатель литературы и резюме на английском, русском и грузинском языках.

3. В статье должны быть освещены актуальность данного материала, методы и результаты исследования и их обсуждение.

При представлении в печать научных экспериментальных работ авторы должны указывать вид и количество экспериментальных животных, применяющиеся методы обезболивания и усыпления (в ходе острых опытов).

4. К статье должны быть приложены краткое (на полстраницы) резюме на английском, русском и грузинском языках (включающее следующие разделы: цель исследования, материал и методы, результаты и заключение) и список ключевых слов (key words).

5. Таблицы необходимо представлять в печатной форме. Фотокопии не принимаются. **Все цифровые, итоговые и процентные данные в таблицах должны соответствовать таковым в тексте статьи.** Таблицы и графики должны быть озаглавлены.

6. Фотографии должны быть контрастными, фотокопии с рентгенограмм - в позитивном изображении. Рисунки, чертежи и диаграммы следует озаглавить, пронумеровать и вставить в соответствующее место текста **в tiff формате**.

В подписях к микрофотографиям следует указывать степень увеличения через окуляр или объектив и метод окраски или импрегнации срезов.

7. Фамилии отечественных авторов приводятся в оригинальной транскрипции.

8. При оформлении и направлении статей в журнал МНГ просим авторов соблюдать правила, изложенные в «Единых требованиях к рукописям, представляемым в биомедицинские журналы», принятых Международным комитетом редакторов медицинских журналов - <http://www.spinesurgery.ru/files/publish.pdf> и http://www.nlm.nih.gov/bsd/uniform_requirements.html В конце каждой оригинальной статьи приводится библиографический список. В список литературы включаются все материалы, на которые имеются ссылки в тексте. Список составляется в алфавитном порядке и нумеруется. Литературный источник приводится на языке оригинала. В списке литературы сначала приводятся работы, написанные знаками грузинского алфавита, затем кириллицей и латиницей. Ссылки на цитируемые работы в тексте статьи даются в квадратных скобках в виде номера, соответствующего номеру данной работы в списке литературы. Большинство цитированных источников должны быть за последние 5-7 лет.

9. Для получения права на публикацию статья должна иметь от руководителя работы или учреждения визу и сопроводительное отношение, написанные или напечатанные на бланке и заверенные подписью и печатью.

10. В конце статьи должны быть подписи всех авторов, полностью приведены их фамилии, имена и отчества, указаны служебный и домашний номера телефонов и адреса или иные координаты. Количество авторов (соавторов) не должно превышать пяти человек.

11. Редакция оставляет за собой право сокращать и исправлять статьи. Корректура авторам не высылается, вся работа и сверка проводится по авторскому оригиналу.

12. Недопустимо направление в редакцию работ, представленных к печати в иных издательствах или опубликованных в других изданиях.

При нарушении указанных правил статьи не рассматриваются.

REQUIREMENTS

Please note, materials submitted to the Editorial Office Staff are supposed to meet the following requirements:

1. Articles must be provided with a double copy, in English or Russian languages and typed or computer-printed on a single side of standard typing paper, with the left margin of **3** centimeters width, and **1.5** spacing between the lines, typeface - **Times New Roman (Cyrillic)**, print size - **12** (referring to Georgian and Russian materials). With computer-printed texts please enclose a CD carrying the same file titled with Latin symbols.

2. Size of the article, including index and resume in English, Russian and Georgian languages must be at least 10 pages and not exceed the limit of 20 pages of typed or computer-printed text.

3. Submitted material must include a coverage of a topical subject, research methods, results, and review.

Authors of the scientific-research works must indicate the number of experimental biological species drawn in, list the employed methods of anesthetization and soporific means used during acute tests.

4. Articles must have a short (half page) abstract in English, Russian and Georgian (including the following sections: aim of study, material and methods, results and conclusions) and a list of key words.

5. Tables must be presented in an original typed or computer-printed form, instead of a photocopied version. **Numbers, totals, percentile data on the tables must coincide with those in the texts of the articles.** Tables and graphs must be headed.

6. Photographs are required to be contrasted and must be submitted with doubles. Please number each photograph with a pencil on its back, indicate author's name, title of the article (short version), and mark out its top and bottom parts. Drawings must be accurate, drafts and diagrams drawn in Indian ink (or black ink). Photocopies of the X-ray photographs must be presented in a positive image in **tiff format**.

Accurately numbered subtitles for each illustration must be listed on a separate sheet of paper. In the subtitles for the microphotographs please indicate the ocular and objective lens magnification power, method of coloring or impregnation of the microscopic sections (preparations).

7. Please indicate last names, first and middle initials of the native authors, present names and initials of the foreign authors in the transcription of the original language, enclose in parenthesis corresponding number under which the author is listed in the reference materials.

8. Please follow guidance offered to authors by The International Committee of Medical Journal Editors guidance in its Uniform Requirements for Manuscripts Submitted to Biomedical Journals publication available online at: http://www.nlm.nih.gov/bsd/uniform_requirements.html
http://www.icmje.org/urm_full.pdf

In GMN style for each work cited in the text, a bibliographic reference is given, and this is located at the end of the article under the title "References". All references cited in the text must be listed. The list of references should be arranged alphabetically and then numbered. References are numbered in the text [numbers in square brackets] and in the reference list and numbers are repeated throughout the text as needed. The bibliographic description is given in the language of publication (citations in Georgian script are followed by Cyrillic and Latin).

9. To obtain the rights of publication articles must be accompanied by a visa from the project instructor or the establishment, where the work has been performed, and a reference letter, both written or typed on a special signed form, certified by a stamp or a seal.

10. Articles must be signed by all of the authors at the end, and they must be provided with a list of full names, office and home phone numbers and addresses or other non-office locations where the authors could be reached. The number of the authors (co-authors) must not exceed the limit of 5 people.

11. Editorial Staff reserves the rights to cut down in size and correct the articles. Proof-sheets are not sent out to the authors. The entire editorial and collation work is performed according to the author's original text.

12. Sending in the works that have already been assigned to the press by other Editorial Staffs or have been printed by other publishers is not permissible.

Articles that Fail to Meet the Aforementioned Requirements are not Assigned to be Reviewed.

ავტორია საშურალებოდ!

რედაქტორი სტატიის წარმოდგენისას საჭიროა დავიცვათ შემდეგი წესები:

1. სტატია უნდა წარმოადგინოთ 2 ცალად, რუსულ ან ინგლისურ ენებზე, დაბეჭდილი სტანდარტული ფურცლის 1 გვერდზე, 3 სმ სიგანის მარცხენა ველისა და სტრიქონებს შორის 1,5 ინტერვალის დაცვით. გამოყენებული კომპიუტერული შრიფტი რუსულ და ინგლისურნოვან ტექსტებში - **Times New Roman (Кириллицა)**, ხოლო ქართულენოვან ტექსტში საჭიროა გამოვიყენოთ **AcadNusx**. შრიფტის ზომა – 12. სტატიას თან უნდა ახლდეს CD სტატიით.

2. სტატიის მოცულობა არ უნდა შეადგენდეს 10 გვერდზე ნაკლებს და 20 გვერდზე მეტს ლიტერატურის სის და რეზიუმების (ინგლისურ, რუსულ და ქართულ ენებზე) ჩათვლით.

3. სტატიაში საჭიროა გამუქდება: საკითხის აქტუალობა; კვლევის მიზანი; საკვლევი მასალა და გამოყენებული მეთოდები; მიღებული შედეგები და მათი განსჯა. ექსპერიმენტული ხასიათის სტატიების წარმოდგენისას ავტორებმა უნდა მიუთითონ საექსპერიმენტო ცხოველების სახეობა და რაოდენობა; გაუტკივარებისა და დაძინების მეთოდები (მწვავე ცდების პირობებში).

4. სტატიას თან უნდა ახლდეს რეზიუმე ინგლისურ, რუსულ და ქართულ ენებზე არანაკლებ ნახევარი გვერდის მოცულობისა (სათაურის, ავტორების, დაწესებულების მითითებით და უნდა შეიცავდეს შემდეგ განყოფილებებს: მიზანი, მასალა და მეთოდები, შედეგები და დასკვნები; ტექსტუალური ნაწილი არ უნდა იყოს 15 სტრიქონზე ნაკლები) და საკვანძო სიტყვების ჩამონათვალი (key words).

5. ცხრილები საჭიროა წარმოადგინოთ ნაბეჭდი სახით. ყველა ციფრული, შემაჯამებელი და პროცენტული მონაცემები უნდა შეესაბამებოდეს ტექსტში მოყვანილს.

6. ფოტოსურათები უნდა იყოს კონტრასტული; სურათები, ნახაზები, დიაგრამები - დასათაურებული, დანორმილი და სათანადო ადგილას ჩასმული. რენტგენოგრამების ფოტოსასლები წარმოადგინეთ პოზიტიური გამოსახულებით **tiff** ფორმატში. მიკროფოტ-სურათების წარწერებში საჭიროა მიუთითოთ ოკულარის ან ობიექტივის საშუალებით გადიდების ხარისხი, ანათალების შედეგის ან იმპრეგნაციის მეთოდი და აღნიშნოთ სურათის ზედა და ქვედა ნაწილები.

7. სამამულო ავტორების გვარები სტატიაში აღინიშნება ინიციალების თანდართვით, უცხოურისა – უცხოური ტრანსკრიპციით.

8. სტატიას თან უნდა ახლდეს ავტორის მიერ გამოყენებული სამამულო და უცხოური შრომების ბიბლიოგრაფიული სია (ბოლო 5-8 წლის სიღრმით). ანბანური წყობით წარმოდგენილ ბიბლიოგრაფიულ სიაში მიუთითეთ ჯერ სამამულო, შემდეგ უცხოელი ავტორები (გვარი, ინიციალები, სტატიის სათაური, ურნალის დასახელება, გამოცემის ადგილი, წელი, ურნალის №, პირველი და ბოლო გვერდები). მონოგრაფიის შემთხვევაში მიუთითეთ გამოცემის წელი, ადგილი და გვერდების საერთო რაოდენობა. ტექსტში კვადრატულ ფრჩილებში უნდა მიუთითოთ ავტორის შესაბამისი N ლიტერატურის სიის მიხედვით. მიზანშეწონილია, რომ ციტირებული წყაროების უმეტესი ნაწილი იყოს 5-6 წლის სიღრმის.

9. სტატიას თან უნდა ახლდეს: ა) დაწესებულების ან სამეცნიერო ხელმძღვანელის წარდგინება, დამოწმებული ხელმოწერითა და ბეჭდით; ბ) დარგის სპეციალისტის დამოწმებული რეცეზია, რომელშიც მითითებული იქნება საკითხის აქტუალობა, მასალის საკმაობა, მეთოდის სანდოობა, შედეგების სამეცნიერო-პრაქტიკული მნიშვნელობა.

10. სტატიის ბოლოს საჭიროა ყველა ავტორის ხელმოწერა, რომელთა რაოდენობა არ უნდა აღემატებოდეს 5-ს.

11. რედაქტორი იტოვებს უფლებას შეასწოროს სტატიას. ტექსტშე მუშაობა და შეჯრება ხდება საავტორო ორიგინალის მიხედვით.

12. დაუშვებელია რედაქტორი ისეთი სტატიის წარდგენა, რომელიც დასაბეჭდიდად წარდგენილი იყო სხვა რედაქტორიაში ან გამოქვეყნებული იყო სხვა გამოცემებში.

აღნიშნული წესების დარღვევის შემთხვევაში სტატიები არ განიხილება.

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EVALUATION OF THE DEEP INSPIRATION BREATH-HOLD TECHNIQUE TO IMPROVE DOSIMETRIC OUTCOMES IN RADIOTHERAPY FOR STAGE III NON-SMALL CELL LUNG CANCER

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Abstract.

Background: Radiotherapy is a key treatment for stage III non-small cell lung cancer (NSCLC), but tumor proximity to critical structures—such as the heart, esophagus, and spinal cord and respiratory motion complicates dose delivery. The Deep Inspiration Breath Hold (DIBH) technique actively controls respiratory motion, potentially improving treatment precision.

Methods: This retrospective study included 56 patients with stage III NSCLC. Each underwent two CT scans: one during free breathing (FB) and one using DIBH. Dosimetric parameters for organs at risk (OARs) were compared between FB (with a 6 mm internal target volume margin) and DIBH plans using paired Student's t-tests.

Results: DIBH increased total lung volume by 28% and reduced heart volume by 12.5%. Lung dose metrics improved significantly with DIBH, including V5, V20, and mean lung dose (all $P < 0.001$). Heart dose parameters (V10, V40, mean dose) also decreased. DIBH significantly reduced both maximum and mean doses to the esophagus and maximum dose to the spinal cord.

Conclusions: In stage III NSCLC, DIBH significantly lowers radiation exposure to OARs and enhances dose delivery accuracy. By expanding lung volume, it may reduce the risk of radiation-induced pneumonitis.

Key words. NSCLC, DIBH, radiotherapy, dosimetry, organs at risk.

Introduction.

Non-small cell lung cancer (NSCLC) accounts for approximately 85% of all lung cancer cases, with nearly 30% of patients presenting at a locally advanced stage at diagnosis [1]. Stage III NSCLC represents a particularly complex and heterogeneous group, characterized by variations in tumor size, local invasion, and lymphatic involvement. Centrally located Stage III NSCLC, in particular, comprises tumors situated near critical mediastinal structures such as the heart, esophagus, and spinal cord. This anatomical configuration poses substantial challenges in radiotherapy planning and delivery, as the therapeutic dose required for tumor control often approaches or exceeds the tolerance thresholds of adjacent organs at risks (OARs). Consequently, achieving optimal dosimetric balance, maximizing tumor coverage while minimizing normal tissue toxicity is a central concern in the management of these patients.

Radiotherapy remains a cornerstone of treatment for Stage III NSCLC, especially in cases deemed unresectable or unsuitable for surgical intervention. Conventional radiation therapy delivered under free-breathing (FB) conditions necessitates the inclusion of additional treatment margins to account for

respiration-induced tumor motion. This approach, however, can result in suboptimal dose distributions and increased exposure to healthy tissues. To address these limitations, advanced techniques such as three-dimensional conformal radiotherapy (3D-CRT) and image-guided radiotherapy (IGRT) have been developed to improve precision and reduce toxicity [2].

Among these innovations, the Deep Inspiration Breath-Hold (DIBH) technique has emerged as a particularly effective strategy. By training patients to hold their breath during deep inspiration, DIBH increases lung volume and displaces mediastinal structures, thereby enhancing geometric separation between the tumor and surrounding OARs. This method has been shown to reduce the internal target volume (ITV), minimize the volume of irradiated lung tissue, and lower the administered dose to critical structures such as the heart, esophagus, and spinal cord [3,4].

Recent clinical evidence supports the utility of DIBH in thoracic radiotherapy. For example, the PUDDING phase II trial demonstrated that DIBH, when combined with daily online adaptive radiotherapy, significantly reduced the incidence of grade ≥ 3 adverse events in patients with NSCLC [5]. Additional dosimetric studies have reported reductions in mean heart dose, lung V20, and spinal cord exposure, reinforcing the potential of DIBH to improve the therapeutic ratio.

The present study aims to compare dosimetric parameters in stage III NSCLC patients receiving radiotherapy under two respiratory condition FB and DIBH. By systematically analyzing treatment plans and dose-volume metrics, this investigation seeks to determine the feasibility and clinical benefit of integrating DIBH into routine practice for high-risk thoracic radiotherapy.

Patients and Methods.

Patients: This retrospective cohort study included 56 patients diagnosed with stage III NSCLC who underwent definitive radiotherapy using the DIBH technique between January 2022 and December 2024. Alongside the lungs, for dosimetric evaluation of the heart and esophagus, patients with histologically confirmed stage III NSCLC, particularly those with centrally located and lower lobe tumors—were selected. Patients were excluded if they had previously received thoracic radiotherapy, were unable to sustain breath-hold for more than 10 seconds, or failed to complete the prescribed course of radiotherapy.

CT simulation, DIBH technique:

All patients underwent non-contrast CT simulation using a dedicated 40-slice Sensation Open scanner (Siemens, Erlangen, Germany). Two CT scans were acquired for each patient: one

under FB conditions and one during DIBH. Scans extended from the mid-neck to the upper abdomen, with a typical acquisition time of approximately 15 seconds per scan.

Prior to CT simulation, patients received structured training in thoracic DIBH. Thoracic DIBH involves coordinated activation of the diaphragm and chest wall muscles during deep inspiration, followed by voluntary breath-hold. The training endpoint was defined as the ability to reproducibly maintain breath-hold at full inspiration (100%) for at least 15 seconds.

During simulation, patients were positioned supine on the CT table and initially guided through quiet tidal breathing. This was followed by verbal coaching to perform a sequence of slow, deep inspiration, expiration, and a second deep breath-hold. Respiratory motion was monitored using the Varian Real-time Position Management (RPM) system (Varian Medical Systems, Palo Alto, CA, USA). Breath-hold amplitude and gating window parameters were individualized based on tumor location and patient performance, with typical values of 3–5 cm for marker displacement (infrared reflector placed below the xiphoid process) and 2–3 mm for gating window width.

Target delineation, OARs, treatment planning and statistical analysis:

The CT dataset was imported into the Eclipse treatment planning system (version 11.0; Varian Medical Systems, USA). To contour the Gross Tumor Volume (GTV)—which includes the primary tumor and pathologically involved lymph nodes—in lung cancer, contrast-enhanced CT and/or PET-CT should be used to delineate metabolically active and anatomically visible tumor regions, excluding atelectasis unless it demonstrates PET avidity. The clinical target volume (CTV) encompassed the GTV, with a uniform expansion margin of 0.5 cm. To account for respiratory motion during free breathing (FB), an internal target volume (ITV) margin of 0.6 cm was added to the CTV. Subsequently, a planning target volume (PTV) margin of 0.3 cm was applied for FB and DIBH plans. All lung cancer patients treated with either DIBH or FB undergo daily image guided radiotherapy (IGRT), with cone beam CT performed before each fraction. This protocol ensures tumor position reproducibility within 2–3 mm, permitting omission of the ITV margin in DIBH and the application of a uniform 3 mm PTV margin directly to the CTV in both techniques. Although a 5 mm margin is commonly used in standard practice, our workflow incorporating daily volumetric IGRT provides sufficient confidence to minimize the risk of geographical miss.

OARs included the heart, lungs, esophagus, and spinal cord. The heart volume was delineated as the entire visible myocardium extending from the apex to the infundibulum, epicardial fat and pericardium. Lung volumes were automatically contoured using the auto-contouring tool within the treatment planning system (TPS). The spinal cord was contoured from the C7 to T12 vertebral levels.

Intensity-Modulated Radiation Therapy (IMRT) treatment plan was generated for each contour using the Anisotropic Analytical Algorithm (AAA). Dose-volume optimization (DVO) was performed to ensure that 95% of the PTV received the full prescription dose of 60 Gy. The maximum dose (D max) within the PTV was restricted to less than 110% of the

prescribed dose.

Dose-volume histograms (DVHs) were created for both FB and DIBH plans. The following dosimetric parameters for OARs were recorded: mean lung dose (D mean), percentage of bilateral lung volume receiving 5 Gy (V5) and 20 Gy (V20), mean heart dose (D mean), percentage of heart volume receiving 10 Gy (V10) and 40 Gy (V40), mean esophageal dose (D mean), esophageal volume receiving 50 Gy (V50), and spinal cord maximum dose (D max).

Dose constraints for OARs were as follows: lung V20 < 35%, lung D mean < 18 Gy, heart V40 < 35%, esophagus V50 < 35%, esophagus D mean < 34 Gy, and spinal cord D max < 46 Gy. All treatment plans met clinical acceptability criteria.

A conventional treatment regimen of 60 Gy delivered in 2 Gy fractions was adopted for this study. Dosimetric parameters assessed under both FB and DIBH conditions included the mean dose (D mean) and maximum dose (D max) to OARs, the percentage of lung volume receiving 5 Gy (V5) and 20 Gy (V20), and the percentage of heart volume receiving 10 Gy (V10) and 40 Gy (V40). The FB parameters served as the baseline control values.

Comparative analysis of lung and heart dose metrics between DIBH and FB was conducted using paired sample Student's t-tests. Pearson correlation coefficients were calculated to evaluate the relationship between lung volume expansion and all recorded OAR parameters. A P-value less than 0.05 was considered indicative of statistical significance.

Results

Patient characteristics: This study included 56 patients, comprising 49 males and 7 females, with a median age of 61 years (range: 52–70 years). All patients were diagnosed with stage III NSCLC. Histopathological analysis revealed that 40% of the cases were squamous cell carcinoma, while the remaining 60% were adenocarcinoma.

Volume comparison:

The total lung volume was $2,857 \pm 94$ mL during FB and $3,950 \pm 196$ mL during DIBH, reflecting a significant increase of 1,093 mL, or approximately 28%, in DIBH acquisitions compared to FB ($P < 0.001$; Table 1). The mean heart volume measured 592 ± 28 mL in FB and 526 ± 22 mL in DIBH. Although heart volume decreased by 12.55% in DIBH relative to FB, this difference did not reach statistical significance ($P = 0.045$). The mean CTV remained consistent across both CT datasets. In contrast, the mean PTV was significantly reduced from 786 ± 28 mL in FB to 498 ± 37 mL in DIBH, representing a 36.6% reduction ($P < 0.001$), primarily attributable to differences in the ITV.

Dosimetric parameters and dose distributions for the PTV and surrounding normal tissues were assessed using cumulative DVHs for both FB and DIBH, as shown in Table 2. Significant improvements in all lung metrics—V5, V20, and mean dose (D mean)—were observed with DIBH compared to FB ($P < 0.001$ for all). Similarly, the heart showed notable reductions in V10, V40, and D mean under DIBH ($P < 0.001$ for all), indicating substantial cardiac sparing. For the esophagus, both D mean and maximum dose (D max) were significantly lower with DIBH,

Table 1. Dosimetric parameters of OAR.

Structure	FB volume (Mean \pm SD)	DIBH volume (Mean \pm SD)	P Value
Lung	2857 \pm 94.3 mL	3950 \pm 198 mL	P < 0.001
Heart	592 \pm 36 mL	526 \pm 22 mL	P = 0.002
CTV	370 \pm 46 mL	370 \pm 46 mL	P = 1.000
PTV	786 \pm 28 mL	498 \pm 37 mL	P < 0.001

FB: Free Breath; DIBH: Deep Inspiration Breath Hold; CTV: Clinical Target Volume; PTV: Planning Target Volume; SD: Standard Deviation.

Table 2. Dosimetric comparison between FB and DIBH.

Organ/Structure	Parameter	FB (Mean \pm SD)	DIBH (Mean \pm SD)	P Value
Total Lung	V5 (%)	57% \pm 1.90	42% \pm 2.11	< 0.001
	V20 (%)	41% \pm 1.33	29% \pm 1.26	< 0.001
	Dmean (Gy)	17 \pm 0.45	14 \pm 0.47	< 0.001
Heart	V10 (%)	46% \pm 3.42	32% \pm 2.98	< 0.001
	V40 (%)	27% \pm 3.13	18% \pm 3.27	< 0.001
	Dmean (Gy)	16 \pm 2.15	10 \pm 1.97	< 0.001
Esophagus	Dmax (Gy)	60 \pm 1.76	54 \pm 1.87	0.002
Spinal Cord	Dmean (Gy)	29 \pm 0.73	22 \pm 0.84	< 0.001
Spinal Cord	Dmax (Gy)	49 \pm 0.56	44 \pm 0.45	0.003

FB: Free Breath; DIBH: Deep Inspiration Breath Hold; SD: Standard Deviation; V5: Percentage Volume Receiving Doses 5 Gy; V20: Percentage Volume Receiving Doses 20 Gy; V40: Percentage Volume Receiving Doses 40 Gy; D mean: Mean Dose; D max: Maximum Dose.

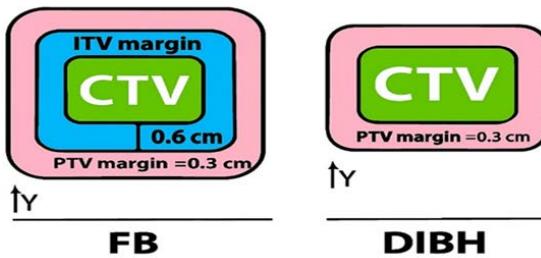


Figure 1. The ITV and PTV margin in DIBH and FB.

ITV: Internal Target Volume; PTV: Planning Target Volume; FB: Free Breath; DIBH: Deep Inspiration Breath Hold.

with D mean showing a highly significant decrease (P < 0.001) and D max also significantly reduced (P = 0.002). The spinal cord exhibited comparable improvements, with a significant reduction in D max (P = 0.003), as detailed in Table 2.

Discussion.

This study assessed the dosimetric impact of DIBH compared to FB in fifty-six patients with stage III NSCLC. Each patient underwent CT simulation under both respiratory conditions to evaluate changes in organ volumes and radiation exposure. DIBH led to a significant increase in total lung volume—approximately 27%—which is consistent with previous studies reporting lung expansion between 45% and 52% during DIBH techniques [6,7]. More recent studies confirm reproducibility of DIBH within 2–3 mm under daily CBCT or surface guidance, supporting margin reduction strategies [8,9]. In VMAT planning, DIBH has been shown to enhance lung sparing and improve conformity [10,11]. The CTV remained unchanged between FB and DIBH scans, as it was derived from the same tumor contours, eliminating inter-scan delineation variability. However, omission of the ITV margin in DIBH planning resulted in a 36.6% reduction in PTV, a finding that aligns with recent DIBH-based lung cancer protocols [5]. This geometric reduction is consistent with modern IGRT workflows that validate smaller margins [9]. We emphasize that the observed

dosimetric advantage results from both anatomical lung expansion during DIBH and geometric reduction of the PTV volume, each contributing independently to dose sparing.

Heart volume decreased significantly under DIBH, from 592 \pm 28 ml in FB to 526 \pm 22 ml, corresponding to a 12.5% reduction. The mean heart dose decreased by 37.5% (10.0 \pm 1.97 Gy vs. 16.0 \pm 2.15 Gy, P < 0.001), with corresponding reductions in V10 and V40. These improvements are influenced by tumor location, target geometry, and the anatomical shifts induced by DIBH [3]. Gong et al. reported that this reduction results from pericardial compression during lung inflation, which displaces the heart posteriorly and inferiorly [12]. More recent VMAT/DIBH studies confirm substantial reductions in mean heart dose and high-dose volumes [8,13]. This anatomical displacement contributes to reduced cardiac exposure, a critical consideration given the established link between heart dose and long-term cardiovascular morbidity [14].

Radiation pneumonitis (RP) remains a common complication in thoracic radiotherapy, particularly in patients with compromised pulmonary function. Dosimetric predictors of RP include V5, V20, and mean lung dose. In our cohort, DIBH reduced mean lung dose by 17.6% (14.0 \pm 0.47 Gy vs. 17.0 \pm 0.45 Gy, P < 0.001), primarily due to increased lung volume and reduced target margins. Similar reductions in V20 and mean lung dose

have been reported in contemporary VMAT+DIBH series [8], which correlate with lower RP risk in modern chemoradiation protocols [15]. These findings are consistent with prior studies demonstrating that DIBH lowers irradiated lung volume and spares critical respiratory regions [8].

The esophagus also showed favourable dose reductions with DIBH. Mean dose decreased by 7.0 Gy (22.0 ± 0.84 Gy vs. 29.0 ± 0.73 Gy, $P < 0.001$), and maximum dose dropped by 6.0 Gy (44.0 ± 1.87 Gy vs. 60.0 ± 1.76 Gy, $P = 0.002$). These metrics are known predictors of radiation-induced esophagitis (RIE). Dehing-Oberije et al. identified D mean and D max as key indicators of acute dysphagia risk [16]. Recent VMAT+DIBH studies also report meaningful reductions in esophageal dose, particularly in centrally located tumors [10], although variability across cohorts remains [17]. In contrast, Marchand et al. reported only a modest reduction in esophageal Dmean with DIBH and negligible change in D max, highlighting variability across patient cohorts and planning techniques [17].

More recent dosimetric studies in NSCLC confirm that DIBH can modestly reduce spinal cord maximum dose, largely due to decreased target margins and favourable anatomical shifts [10,15]. VMAT-based DIBH planning has further shown incremental sparing of the spinal cord, providing an additional safety margin even though the clinical impact is less pronounced compared to lung and heart endpoints [10]. In our study, DIBH reduced spinal cord maximum dose by 5.0 Gy (44.0 ± 0.45 Gy vs. 49.0 ± 0.56 Gy, $P = 0.003$), likely due to reduced target margins and favorable anatomical shifts. Similar incremental sparing has been observed in VMAT+DIBH protocols [15], providing additional safety margins even though clinical impact is modest compared to lung and heart endpoints. The proximity of the spinal cord to the esophagus may also contribute to parallel dose reductions.

Emerging literature emphasizes heterogeneity of DIBH benefits by tumor site, with centrally located and lower lobe tumors showing greater OAR sparing [8]. Stratified analyses by tumor location may therefore provide further insight into patient selection and optimization of DIBH protocols.

Conclusion.

This study demonstrates that the DIBH technique offers significant dosimetric advantages over FB in the radiotherapy of stage III NSCLC. DIBH effectively increases lung volume, reduces ITV, and consequently decreases PTV, leading to substantial reductions in radiation exposure to critical organs. Notably, mean doses to the lungs, heart, esophagus, and spinal cord were significantly lower with DIBH, contributing to improved organ sparing and potentially reduced risk of radiation-induced toxicities. These benefits are particularly relevant in minimizing the likelihood of radiation pneumonitis, cardiac complications, and esophageal injury. While the study is limited by its single-center design and modest sample size, the findings support the integration of DIBH into routine clinical practice for eligible patients, emphasizing the importance of careful patient selection and respiratory coaching during simulation and treatment delivery.

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ღრმა ინსპირაციის დროს სუნთქვის შეკავების (DIBH) ტექნიკის შეფასება III სტადიის არაწვრილუჯრედოვანი ფილტვის კიბოს (NSCLC) რადიოთერაპიის დოზიმეტრიული შედეგების გასაუმჯობესებლად

ფონი: რადიოთერაპია წარმოადგენს III სტადიის არამცირე უჯრედიანი ფილტვის კიბოს (NSCLC) მკურნალობის ძირითად მეთოდს. თუმცა, სიმსივნის სიახლოვე პრიტიკულ სტრუქტურებთან—როგორიცაა გული, საყლაპავი მილი და ზურგის ტვინი—და სუნთქვითი მოძრაობა ართულებს დოზის ზუსტ მიწოდებას. ღრმა ინსპირაციის დროს სუნთქვის შეკავების (DIBH) ტექნიკა აქტიურად აკონტროლებს სუნთქვით მოძრაობას და ხელს უწყობს მკურნალობის სიზუსტის გაუმჯობესებას. მეთოდები: რეტროსპექტულ კვლევაში ჩართული იყო 56 პაციენტი III სტადიის NSCLC-ით. თითოეულს ჩაუტარდა ორი კომპიუტერული ტომოგრაფია (CT): ერთი თავისუფალი სუნთქვის (FB) დროს და მეორე DIBH ტექნიკის გამოყენებით. რისკის ქვეშ მყოფი ორგანოების (OARs) დოზიმეტრიული პარამეტრები შედარებული იქნა FB და (6 მმ შიდა სამიზნე მოცულობის მარჯით) DIBH გეგმებს შორის, Student-ის დაწყვილებული t-ტესტის გამოყენებით. შედეგები: DIBH-ით ფილტვის საერთო მოცულობა 28%-ით გაიზარდა, ხოლო გულის მოცულობა 12.55%-ით შემცირდა. ფილტვის დოზიმეტრიული მაჩვენებლები მნიშვნელოვნად გაუმჯობესდა DIBH-ით, მათ შორის V5, V20 და საშუალო ფილტვის დოზა (ყველა $P < 0.001$). გულის დოზის მაჩვენებლები (V10, V40, საშუალო დოზა) ასევე შემცირდა. DIBH-მა მნიშვნელოვნად შეამცირა როგორც საყლაპავი მილის მაქსიმალური და საშუალო დოზა, ასევე ზურგის ტვინის მაქსიმალური დოზა. დასკვნები: III სტადიის NSCLC-ის მქონე პაციენტებში DIBH ტექნიკა მნიშვნელოვნად ამცირებს რადიოაქტიური დასხივების ზემოქმედებას

OARs-ზე და აუმჯობესებს დოზის მიწოდების სიზუსტეს. ფილტვის მოცულობის გაზრდით, ეს მიდგომა შესაძლოა შეამციროს რადიოთერაპიის შედეგად გამოწვეული პნევმონიტის რისკი. საკვანძო სიტუაცია: NSCLC; DIBH; რადიოთერაპია; დოზიმეტრია; რისკის ქვეშ მყოფი ორგანოები.

ОЦЕНКА ТЕХНИКИ ГЛУБОКОГО ВДОХА С ЗАДЕРЖКОЙ ДЫХАНИЯ (DIBH) ДЛЯ УЛУЧШЕНИЯ ДОЗИМЕТРИЧЕСКИХ ПОКАЗАТЕЛЕЙ ПРИ ЛУЧЕВОЙ ТЕРАПИИ НЕМЕЛКОКЛЕТОЧНОГО РАКА ЛЁГКОГО (NSCLC) III СТАДИИ

Введение: Лучевая терапия остаётся основным методом лечения не мелкоклеточного рака лёгкого (NSCLC) III стадии. Однако близость опухоли к жизненно важным структурам — таким как сердце, пищевод и спинной мозг- а также дыхательные движения затрудняют точную доставку дозы. Техника глубокого вдоха с задержкой дыхания (DIBH) позволяет активно контролировать дыхательные движения, потенциально повышая точность лечения.

Методы: В ретроспективное исследование были включены 56 пациентов с NSCLC III стадии. Каждому пациенту были выполнены два КТ-сканирования: одно в условиях свободного дыхания (FB) и другое с применением техники DIBH. Дозиметрические параметры для органов риска (OARs) сравнивались между планами FB (с внутренним запасом объёма цели 6 мм) и DIBH с использованием парного t-теста Стьюдента.

Результаты: При DIBH общий объём лёгких увеличился на 28%, а объём сердца уменьшился на 12,5%. Показатели дозы для лёгких значительно улучшились: V5, V20 и средняя доза (все $P < 0,001$). Также наблюдалось снижение дозы на сердце: V10, V40 и средняя доза. DIBH значительно снизил как максимальную, так и среднюю дозу на пищевод, а также максимальную дозу на спинной мозг.

Выводы: У пациентов с NSCLC III стадии техника DIBH значительно снижает лучевую нагрузку на органы риска (OARs) и повышает точность доставки дозы. За счёт увеличения объёма лёгких данный подход может способствовать снижению риска лучевого пневмонита.

Ключевые слова: NSCLC; DIBH; лучевая терапия; дозиметрия; органы риска