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High-Dose-Rate Brachytherapy Combined with Immunotherapy for Advanced Poorly Differentiated Pulmonary Sarcomatoid Carcinoma: A Case Report and Literature Review

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Abstract: The background of this paper is Pulmonary sarcomatoid carcinoma (PSC) is a rare and aggressive subtype of non-small cell lung cancer that is resistant to conventional treatments. High-dose-rate (HDR) combined with immune checkpoint inhibitors (ICIs) may be a promising treatment modality for advanced PSC. *The main situation of the case is about a* 56-year-old male with advanced poorly differentiated PSC with brain metastasis (T4N2M1b, stage IVA) received cranial radiotherapy and two cycles of platinum-based chemotherapy, followed by HDR brachytherapy (30 Gy in a single fraction) to the left lung tumor using an iridium-192 source. Partial remission was achieved after subsequent treatment with atezolizumab, an immune checkpoint inhibitor. He maintained a progression-free state for nearly 30 months until experiencing progression of intracranial lesions, while the lung lesions remained in partial remission. This case demonstrates the potential synergistic effects of combining HDR brachytherapy with immunotherapy in treating advanced PSC. The durable response observed highlights the rationale for further exploration of this innovative therapeutic strategy. Prospective studies are needed to validate these findings and optimize treatment approaches.

1. Introduction

Pulmonary sarcomatoid carcinoma (PSC) is a rare and highly aggressive subtype of non-small cell lung cancer (NSCLC) that poses significant therapeutic challenges due to its resistance to conventional treatments. PSC is characterized by a biphasic morphology, consisting of both epithelial and sarcomatoid components, with the latter being a hallmark of this tumor type. The prognosis of PSC is poor, with a 9.9 months median survival time rangs from 7.6 to 12.6 months and a 5-year

survival rate below 20% [1,2].

Treatment options for PSC are limited and often unsuccessful. Although surgery is the most effective treatment for early-stage PSC, most patients have advanced disease by the time of diagnosis and therefore miss the opportunity for surgery [3]. The standard first-line therapy for advanced PSC is platinum-based chemotherapy with a 16.5% response rate and median progression-free survival (PFS)of 2 months [4]. Radiotherapy is commonly used in palliative care of patients with PSC, however its effect on improving survival is limited [5].

Recently, the introduction of immunotherapy, mainly ICIs, has transformed the treatment paradigm of numerous malignancies including NSCLC. ICIs such as anti-programmed cell death 1 (PD-1) or programmed death-ligand 1 (PD-L1) have shown efficacy in prolonging survival and enhancing quality of life among patients diagnosed with advanced NSCLC [6-8]. However, there has been little investigation into the potential effectiveness of ICIs in treating PSC; Existing clinical research and evidence are limited [9,10].

HDR brachytherapy, a kind of short-distance radiotherapy, has been showed to be useful in local control and treatment in advanced NSCLC [11,12]. Precise radiation targeting limits dose to tumor sites only. This protects normal organs while improving disease control and reducing side effects. Furthermore, therapeutic doses of radiation caused by HDR-brachytherapy might enhance its immune modulation thus synergizing with immunotherapy. Progress has been made in combining radiotherapy and immunotherapy for advanced NSCLC. HDR brachytherapy combined with ICIs may also effectively treat advanced PSC.

Here, we report a unique case of treating an advanced undifferentiated PSC with HDR brachytherapy and immunotherapy, which resulted in a PFS of 30 months. To our knowledge, this is the first attempt to combine HDR brachytherapy and immunotherapy in advanced PSC. We hope that this case report will inspire further research into the potential synergistic effects of combining HDR brachytherapy with immunotherapy in the treatment of advanced PSC. Also, prospective studies with larger patient cohorts are needed to validate these findings, investigate the underlying mechanisms and optimize treatment strategies for advanced PSC.

2. Case presentation

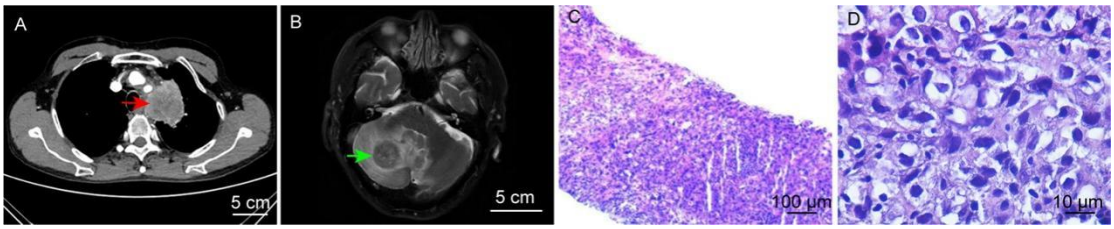

Fig.1 The imaging and pathological examination of the patient.

(A) Chest CT in March 6, 2022 showed a mass-like soft tissue density in the left upper lobe adjacent to the mediastinum, measuring approximately 5.1 ×7.1 cm, with indistinct borders with the mediastinum (indicated by the red arrows). (B) Head MRI initially showed a slightly hyperdense ring-shaped lesion (approximately 2.3 cm) in the right cerebellar hemisphere, with heterogeneous density and surrounding edema (indicated by the green arrows). The fourth ventricle was compressed, suggestive of a metastatic lesion. (C, D) Pathological image analysis and immunohistochemical profile: CD56 (−), CgA (−), CK (Pan) (+), CK 5/6 (−), Ki-67 (+, approximately 60%), LCA (−),

Napsin A (−), NKX 3.1 (−), P40 (−), Syn (−), TTF-1 (−), Vimentin (+).

A 56-year-old male patient presented to the hospital with a history of headaches persisting for more than two days. A comprehensive examination, including a chest computed tomography (CT) scan dated March 6, 2022, revealed the following: A lobulated soft tissue density mass adjacent to the mediastinum in the upper lobe of the left lung, measuring approximately 5.1 × 7.1 cm, with unclear margins with the mediastinum (Fig. 1A); multiple solid nodules in the right lung, ranging from 0.5-1.2 cm in diameter, consistent with intrapulmonary metastases; and bilateral pulmonary emphysema with bullae formation. Enlarged mediastinal lymph nodes were observed in the right lung, with the largest measuring 1.8 cm in short-axis diameter, indicating nodal metastasis (N2 disease). Brain MRI indicated a ring-like slightly hyperdense lesion approximately 2.3 cm in diameter in the right cerebellar hemisphere, with uneven density, surrounding edema, and compression of the fourth ventricle, suggestive of metastatic disease (Fig. 1B). Biopsy and subsequent histopathological examination of lung tumor tissue confirmed poorly differentiated sarcomatoid lung carcinoma. (Fig. 1C, D). The patient was staged as T4N2M1b, stage IVA according to the AJCC 8th edition, with T4 classification due to invasion of mediastinal structures, N2 due to ipsilateral mediastinal lymph node involvement, and M1b due to single extrathoracic metastasis in the brain [13].While the patient had no history of smoking or hereditary disorders.

Given the patient's oligometastatic presentation with a single brain metastasis and primary lung tumor, a multidisciplinary tumor board consisting of medical oncologists, radiation oncologists, thoracic surgeons, and radiologists convened to discuss potential curative-intent treatment strategies. After comprehensive evaluation of the patient's clinical status, imaging findings, and pathology results, the board recommended an aggressive multimodal approach with curative intent despite the stage IVA classification.

After ruling out contraindications for chemotherapy and radiotherapy, he received two cycle of the TP chemotherapy regimen (paclitaxel albumin 260 mg/m ^{2}IV on day 1, cisplatin 75 mg/m ^{2}IV on day 1, every 21 days, with a body surface area of 1.65 m ^{2}) and cranial radiotherapy on March 18 and April 11, 2022, respectively. However, there was no significant change in the pulmonary lesions post-chemotherapy.

Following detailed explanations to the patient and his family about the proposed treatment plan and obtaining their informed consent, we performed HDR brachytherapy on the patient's left lung tumor on May 11, 2022. The HDR brachytherapy procedure utilized an iridium-192 (192 Ir) source, which was delivered through catheters placed directly into the tumor under CT guidance (Fig. 2A). The treatment planning system was used to optimize the dose distribution to the target volume while minimizing exposure to surrounding healthy tissues. A total dose of 30 Gy was prescribed to the gross tumor volume (GTV), delivered in a single fraction at a high-dose rate of 10 Gy per minute. The patient tolerated the procedure well without any immediate complications. The first post-brachytherapy chest CT scan, performed four weeks after the procedure on June 8, 2022, showed initial tumor response with a 15% reduction in the primary tumor's longest diameter, while mediastinal lymphadenopathy remained stable. Subsequent treatment with atezolizumab 200 mg intravenously every 21 days obtained a significant reduction in the size of the lesions, achieving partial remission. To further address the primary lung tumor and involved mediastinal lymph nodes and to consolidate the therapeutic gains, the patient received palliative radiotherapy to the left lung and mediastinum on October 11, 2022, delivering a total dose of 60 Gy in 2 Gy fractions over 30 fractions. Maintenance treatment with atezolizumab 200 mg every 21 days was continued, and during

the entire course of treatment, the patient did not experience any radiotherapy or immunotherapy-related complications. The patient decided to discontinue atezolizumab and other subsequent treatments after December 2022 due to family financial reasons. Subsequently, our medical team conducted regular imaging follow-up on the patient every 3 months. Following treatment discontinuation, our medical team conducted regular imaging follow-up on the patient every 3 months. Brain MRI was conducted quarterly and showed stable intracranial disease until December 2024. The patient maintained progression-free status for 30 months after initial HDR brachytherapy, an exceptional outcome for this aggressive malignancy.

In December 2024, brain MRI revealed progression of the cerebellar metastasis, which had enlarged from 1.0 cm (post-initial cranial radiotherapy) to 2.5 cm, with associated edema and mass effect. A comprehensive restaging at this time confirmed continued partial remission of the thoracic disease. Upon detection of intracranial progression, our multidisciplinary tumor board recommended stereotactic radiosurgery (15 Gy in single fraction) to the cerebellar lesion and resumption of immunotherapy, and the patient is currently being counseled about these treatment options. As of the most recent follow-up, the patient's lung tumor lesions were effectively controlled, with no signs of recurrence (Fig. 2B−D).

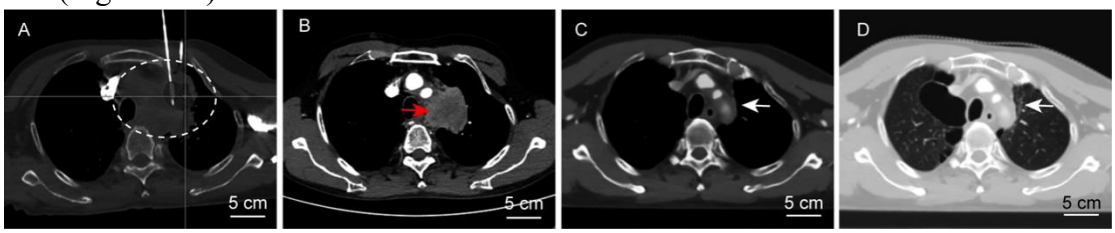

Fig.2 The HDR brachytherapy for lung tumors of this patient and follow-up imaging after treatment.

(A) Under CT guidance, HDR brachytherapy was performed on the patient's left lung tumor. (B) Before treatment, chest CT showed that the tumor in the left upper lobe adjacent to the mediastinum (indicated by the red arrows). (C, D) During the follow-up from March, 2022 to April, 2024, the lesion in the left lung was in partial remission.

Throughout the treatment course, the patient's symptoms and quality of life were closely monitored. Prior to treatment, the patient reported severe headaches, fatigue, occasional dyspnea on exertion, and a persistent dry cough. Following cranial radiotherapy, his headaches resolved completely within two weeks. The patient experienced grade 2 fatigue and grade 1 nausea during chemotherapy, which were managed with supportive medications and resolved without dose reduction. During HDR brachytherapy, the patient reported mild chest discomfort during catheter placement, which resolved spontaneously within 24 hours post-procedure. No radiation pneumonitis or esophagitis was observed in the subsequent weeks. After initiating atezolizumab immunotherapy, the patient developed grade 1 pruritus and a mild rash on his trunk which resolved with topical corticosteroids. Notably, his respiratory symptoms improved significantly by the third cycle of immunotherapy, with complete resolution of cough and improved exercise tolerance. The patient was able to resume most of his daily activities by December 2022, reporting a marked improvement in his overall quality of life using the EORTC QLQ-C30 questionnaire (global health status/QoL score improved from 45 at baseline to 78). His performance status improved from ECOG 2 at diagnosis to ECOG 1 after combined treatment. The patient tolerated the entire treatment regimen remarkably well, with no grade 3 or higher adverse events observed during the 30-month treatment period. When intracranial progression was detected

in December 2024, the patient reported the return of mild headaches and occasional dizziness, though less severe than at initial presentation.

The patient underwent a comprehensive treatment regimen that included cranial radiotherapy, platinum-based chemotherapy, HDR brachytherapy, and immunotherapy with atezolizumab. Follow-up imaging in October 2022 revealed a significant reduction in mediastinal lymph node size, with the largest node measuring only 0.8 cm in short-axis diameter, indicating an excellent response to the combined therapeutic approach. By January 2023, the previously enlarged mediastinal lymph nodes had completely normalized, demonstrating complete response to therapy. As illustrated in the treatment timeline (Fig.3), this multimodal approach resulted in a progression-free survival (PFS) of nearly 30 months—a remarkable outcome for advanced PSC given its typically aggressive nature. However, during a follow-up evaluation in December 2024, progression of the intracranial lesions was detected. Head MRI performed on December 24, 2024, showed an enlarged nodular lesion with heterogeneous enhancement in the right cerebellar hemisphere, accompanied by increased surrounding edema and a significant mass effect. In response, the patient was recommended to undergo additional radiotherapy targeting the intracranial lesions along with adjunctive immunotherapy. Notably, the lung lesions have maintained partial remission status throughout this period and continue to be well-controlled to the present day.

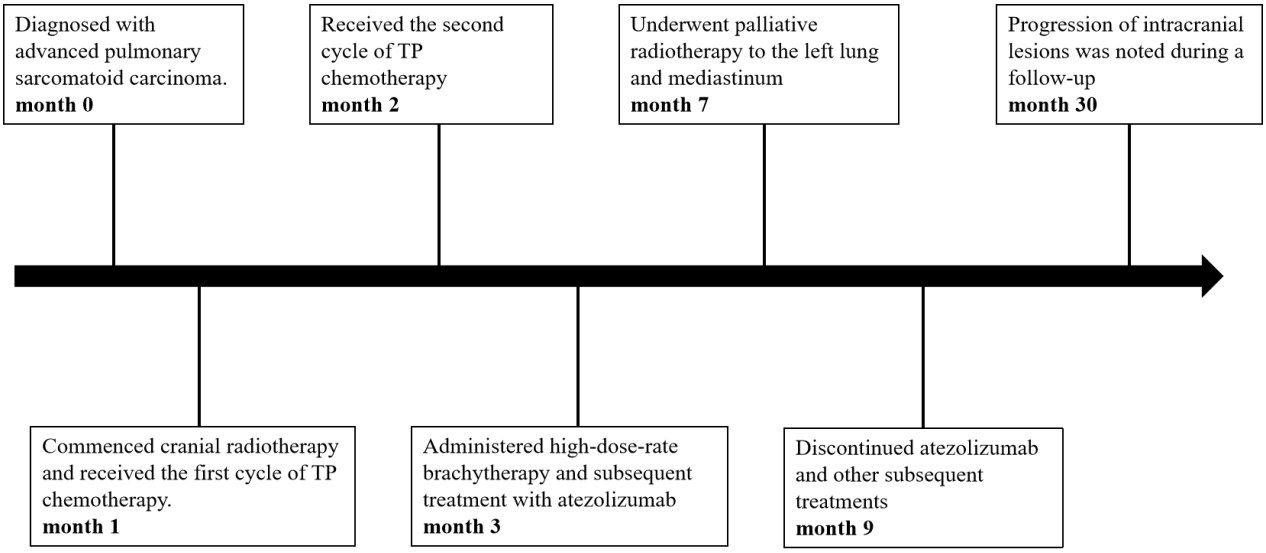

Fig. 3 The timeline of diagnosis, treatment and follow-up to the patient.

3. Discussion

This case report introduces a new method of treatment by the combination of HDR brachytherapy and immunotherapy for advanced undifferentiated PSCs. By using HDR brachytherapy in combination with immunotherapy, the patient responded well to this treatment and remained progression-free for 30 months. This satisfactory result suggests that radiation therapy can work together with immunotherapy to improve treatment outcomes for patients with PSC.

Several studies have shown that the combination of radiotherapy and immunotherapy is more effective in treating NSCLC than either therapy alone [14-16]. This suggests a synergistic anti-cancer effect between the two treatment modalities. The proposed mechanism involves radiation-induced immunogenic cell death, which enhances tumor antigen visibility to the immune system, releasing

antigens that could be taken up by antigen presenting cells and used to activate T lymphocytes within tumors or draining lymph nodes. In addition, radiotherapy may induce local inflammation thereby recruiting effector cells such as macrophages, dendritic cells and NK cells into the tumor microenvironment [17]. These effects could prime an adaptive immune response against cancer cells, potentially leading to not only local control but also systemic abscopal effects. With regards to this particular case, it is possible that therapeutic doses delivered by HDR brachytherapy could have augmented radiation's immunomodulatory potential so as to be synergistic with atezolizumab an immune checkpoint inhibitor.

In the case discussed above, HDR brachytherapy was employed to ensure targeted delivery of high radiation doses directly into the tumor while sparing normal surrounding tissues. This localized approach might have contributed significantly towards better outcomes since it would enhance control over local disease while reducing toxicity associated with systemic therapy or broad field external beam irradiation. Furthermore, High-dose-rate, single-fraction regimens are hypothesized to induce direct DNA damage and generate immunogenic effects which are likely responsible for observed responses in both preclinical models as well patients treated with such regimens [18,19].

The selection of HDR brachytherapy over other local consolidative treatments in this case was based on several important considerations. For centrally located tumors such as this patient's lesion (adjacent to the mediastinum in the left upper lobe), HDR brachytherapy offers unique advantages compared to other modalities. Surgical resection was contraindicated due to the advanced stage (T4N2M1b, stage IVA) and central location with mediastinal involvement. Stereotactic body radiation therapy (SBRT), while effective for peripheral lesions, poses significant risks for central tumors due to potential severe toxicities including fatal hemorrhage, bronchial stenosis, and esophageal injury. Conventional external beam radiotherapy typically delivers lower biologically effective doses and requires protracted treatment courses over 6-7 weeks, which may delay systemic therapy and increase treatment burden.

HDR brachytherapy has emerged as an established technique for managing central lung malignancies, with several studies demonstrating local control rates of 60-85% at 1 year. The rapid dose fall-off characteristic of brachytherapy allows for delivery of ablative doses to the tumor while respecting tolerance doses of adjacent critical structures. This dose distribution advantage is particularly relevant for centrally located tumors where conventional radiotherapy approaches must compromise between tumor control and normal tissue toxicity.

The current treatment landscape for PSC has evolved significantly beyond conventional cytotoxic chemotherapy. Recent molecular profiling studies have identified MET exon 14 skipping mutations in 20-35% of PSC cases, considerably higher than in conventional NSCLC. Targeted therapies such as capmatinib and tepotinib have demonstrated impressive response rates (40-60%) in this molecular subset. Immunotherapy has also shown particular promise in PSC, with retrospective analyses indicating higher response rates to PD-1/PD-L1 inhibitors compared to conventional NSCLC, likely related to the higher tumor mutational burden and PD-L1 expression frequently observed in this histology.

Combination approaches have further expanded treatment options. Chemotherapy plus immunotherapy combinations (as demonstrated in KEYNOTE-189 and IMpower150 trials) have shown improved survival outcomes compared to chemotherapy alone. Anti-angiogenic therapy (bevacizumab, ramucirumab) combined with immunotherapy represents another promising approach, potentially enhancing immunotherapy efficacy by normalizing tumor vasculature and improving

immune cell infiltration. The synergistic interaction between local ablative radiotherapy and immunotherapy, as observed in our case, represents an emerging paradigm that may be particularly beneficial in aggressive histologies like PSC.

The integration of HDR brachytherapy with modern systemic therapies, especially immunotherapy, leverages the potential synergistic effects between local and systemic treatments. The immunogenic cell death induced by high-dose radiation can enhance antigen presentation, increase T-cell infiltration, and potentially overcome resistance mechanisms to immunotherapy, transforming the tumor microenvironment from "cold" to "hot." This radiation-induced immunomodulation may explain the exceptional and durable response observed in our patient despite having an aggressive histological subtype that typically demonstrates limited responsiveness to conventional therapies.

It is worth noting that the patient initially presented with oligometastatic disease, characterized by a solitary brain metastasis and the primary lung lesion. This presentation prompted our multidisciplinary tumor board to consider a potentially curative treatment approach despite the stage IVA classification. Emerging evidence suggests that aggressive local therapy to all sites of visible disease combined with effective systemic therapy can achieve long-term disease control or even cure in selected patients with oligometastatic NSCLC. In our case, the combination of cranial radiotherapy for the brain metastasis, HDR brachytherapy for the primary lung tumor, and consolidative external beam radiotherapy to the thorax, followed by maintenance immunotherapy, represents a comprehensive strategy aimed at both local and systemic disease control. The remarkable 30-month progression-free interval achieved in this case of PSC, a histologically aggressive variant with typically poor outcomes, underscores the value of multidisciplinary evaluation and aggressive multimodality treatment for patients with oligometastatic disease. Throughout the treatment course and follow-up period, the patient's case was regularly reviewed by our multidisciplinary tumor board to assess response and adjust therapeutic strategies as needed.

However, it is important to acknowledge that the current supporting evidence for the combination of radiotherapy and immunotherapy in PSC is limited. Even though this example provides good insights into how well this approach might work, it’s based on what happened to one person so it can’t be taken as a general rule for all people with PSC. In order to confirm these results and work out the best way of treating the condition, more studies involving large numbers of patients who have been followed up over time need to take place. Future research should focus on elucidating the optimal timing, dosing, and sequencing of radiotherapy and immunotherapy in PSC. Additionally, the identification of predictive biomarkers and the exploration of novel immunotherapeutic agents may further enhance treatment outcomes. The incorporation of other treatment modalities, such as targeted therapy or chemotherapy, into the combination regimen may also need more investigation.

4. Conclusion

In conclusion, our case demonstrates the strong potential of HDR brachytherapy combined with immunotherapy for treating the advanced poorly differentiated PSC. However, it is important to note that the evidence is currently limited, prospective studies with larger patient cohorts are needed to confirm these findings and assess the efficacy and safety of this therapy.

Abbreviations

PSC: Pulmonary sarcomatoid carcinoma

NSCLC: Non-small cell lung cancer
ICIs: Immune checkpoint inhibitors
PD-1: Programmed cell death protein 1
PD-L1: Programmed death-ligand 1
HDR: High-dose-rate
GTV: Gross tumor volume
IV: Intravenous
TP: Paclitaxel and cisplatin
cGy: Centigray
MRI: Magnetic resonance imaging
CT: Computed tomography
AJCC: American Joint Committee on Cancer
PFS: Progression-free survival

Ethics approval and consent to participate

This study was reviewed and approved by the local ethics committee of the second people's hospital of Neijiang.

Consent for publication

Written informed consent was obtained from the patient for publication of this case report and any accompanying images. A copy of the written consent is available for review by the Editor-in-Chief of this journal.

Author contributions

Conception: zhengduan. Lin, Y. Xie. Design of the work: Q. Geng, X. L. Yu. Acquisition, analysis, or interpretation of data: zhengduan. Lin, Y. Xie, X. L. Yu. Writing: original draft: L.Yu.Writing—revising & editing: zhengduan. Lin.

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Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Application of the CARE Checklist

According to the CARE guidelines for case reports, we have thoroughly reviewed our manuscript against the checklist. Among the items, 5d (relevant past interventions and their outcomes) and 12 (patient perspective) were not applicable to this case report, as the patient had no history of tumor-related treatments, and we were unable to obtain the patient's subjective evaluation of the treatment experience. Additionally, although item 8b (diagnostic challenges) was not discussed in detail within the manuscript, the patient's diagnostic process was relatively smooth without encountering any particular difficulties, and thus no further elaboration was made. Apart from the aforementioned three items, the report covers all other contents required by the CARE guidelines.

Additional information

No additional information is available for this paper.

References

[1] Li Y, Zhang L, Jiang J, et al. [Clinical Characteristics and Prognostic Analysis of 38 Patients with Pulmonary Sarcomatoid Carcinoma] [J]. Zhongguo Fei Ai Za Zhi, 2015, 18(9): 537-542.

[2] Maneenil K, Xue Z, Liu M, et al. Sarcomatoid Carcinoma of the Lung: The Mayo Clinic Experience in 127 Patients[J]. Clin Lung Cancer, 2018, 19(3): e323-e333.

[3] Li X, Wu D, Liu H, et al. Pulmonary sarcomatoid carcinoma: progress, treatment and expectations[J]. Ther Adv Med Oncol, 2020, 12: 1758835920950207.

[4] Vieira T, Girard N, Ung M, et al. Efficacy of first-line chemotherapy in patients with advanced lung sarcomatoid carcinoma [J]. J Thorac Oncol, 2013, 8(12): 1574-1577.

[5] Lee C W, Kim B H, Kim H J. Clinical outcomes of radical radiotherapy for pulmonary sarcomatoid carcinoma[J]. Radiat Oncol J, 2023, 41(3): 163-171.

[6] Hong M, Lee S W, Cho B C, et al. Multiplex analysis for the identification of plasma protein biomarkers for predicting lung cancer immunotherapy response[J]. Ther Adv Med Oncol, 2024, 16: 17588359241254218.

[7] Reck M, Rodr ́guez-Abreu D, Robinson A G, et al. Pembrolizumab versus Chemotherapy for PD-L1-Positive Non-Small-Cell Lung Cancer [J]. N Engl J Med, 2016, 375(19): 1823-1833.

[8] Zhou Y, Zhang Y, Guo G, et al. Nivolumab plus ipilimumab versus pembrolizumab as chemotherapy-free, first-line treatment for PD-L1-positive non-small cell lung cancer[J]. Clin Transl Med, 2020, 10(1): 107-115.

[9] Domblides C, Leroy K, Monnet I, et al. Efficacy of Immune Checkpoint Inhibitors in Lung Sarcomatoid Carcinoma[J]. J Thorac Oncol, 2020, 15(5): 860-866.

[10] Zhang L, Lin W, Yang Z, et al. Multimodality Treatment of Pulmonary Sarcomatoid Carcinoma: A Review of Current State of Art [J]. J Oncol, 2022, 2022: 8541157.

[11] Skowronek J. Brachytherapy in the treatment of lung cancer - a valuable solution[J]. J Contemp Brachytherapy, 2015, 7(4): 297-311.

[12] Xiang L, Ren P R, Li H X, et al. Effect of 3-Dimensional Interstitial High-Dose-Rate Brachytherapy With Regional Metastatic Lymph Node Intensity-Modulated Radiation Therapy in Locally Advanced Peripheral Non-Small Cell Lung Cancer: 5-Year Follow-up of a Phase 2 Clinical Trial[J]. Int J Radiat Oncol Biol Phys, 2023, 115(2): 347-355.

[13] Edition S, Edge S, Byrd D. AJCC cancer staging manual. AJCC cancer staging manual, 2017.

[14] Theelen W, Peulen H M U, Lalezari F, et al. Effect of Pembrolizumab After Stereotactic Body Radiotherapy vs Pembrolizumab Alone on Tumor Response in Patients With Advanced Non-Small Cell Lung Cancer: Results of the PEMBRO-RT Phase 2 Randomized Clinical Trial[J]. JAMA Oncol, 2019, 5(9): 1276-1282.

[15] Yu S, Wang Y, He P, et al. Effective Combinations of Immunotherapy and Radiotherapy for Cancer Treatment[J]. Front Oncol, 2022, 12: 809304.

[16] Zhang Z, Liu X, Chen D, et al. Radiotherapy combined with immunotherapy: the dawn of cancer treatment[J]. Signal Transduct Target Ther, 2022, 7(1): 258.

[17] Golden E B, Chhabra A, Chachoua A, et al. Local radiotherapy and granulocyte-macrophage colony-stimulating

factor to generate abscopal responses in patients with metastatic solid tumours: a proof-of-principle trial[J]. Lancet Oncol, 2015, 16(7): 795-803.
[18] Jin W J, Zangl L M, Hyun M, et al. ATM inhibition augments type I interferon response and antitumor T-cell immunity when combined with radiation therapy in murine tumor models[J]. J Immunother Cancer, 2023, 11(9).
[19] Tateishi Y, Takeda A, Horita N, et al. Stereotactic Body Radiation Therapy With a High Maximum Dose Improves Local Control, Cancer-Specific Death, and Overall Survival in Peripheral Early-Stage Non-Small Cell Lung Cancer[J]. Int J Radiat Oncol Biol Phys, 2021, 111(1): 143-151.