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Utilizing Online Adaptive MRI-Guided Stereotactic Body Radiotherapy for the Treatment of Pancreatic and Intra-Abdominal Cancers

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Abstract: ***The utilization of a linear accelerator in conjunction with an MRI holds significant promise for advancing MRI-guided stereotactic body radiation therapy. Previous studies predominantly relied on manufacturer-specified MRI sequences, particularly T2 Weighted, facing challenges in identifying organs at risk (OAR) and addressing pancreatic and intra-abdominal cancers. This research introduces a novel approach by harnessing the effectiveness of a T1 Weighted sequence to improve tumor and OAR visibility during online adapted-to-position (ATP) and adapted-to-shape (ATS) planning in MRI-guided radiation therapy. A cohort of 30 patients, including 20 with pancreatic cancer and 10 with intra-abdominal cancer, underwent simulations for planning before embarking on multi-fractionated treatment. The incorporation of T1 Weighted imaging significantly enhanced tumor and contouring precision, enabling swift and accurate planning during ATP and ATS. Plan quality for all 26 patients depended on the proximity of OAR to the target tumor, with gross tumor volume D90% and planned target volume D90% achieving 96 ± 5% and 92 ± 9%, respectively. The adoption of T1 Weighted imaging, with a reduced imaging time of approximately 120 seconds compared to 360 seconds for T2 Weighted imaging, not only minimized treatment margins for OAR sparing but also improved tumor visualization and reduced uncertainties in target/OAR demarcation. In the initial 20 patients, the average duration of MRI-guided radiation therapy was 55 ± 15 minutes for ATP and 79 ± 20 minutes for ATS. This study underscores the potential of MRI-guided radiation therapy in Asia, presenting an improved approach for addressing intra-abdominal and pancreatic cancer. T1 Weighted imaging emerges as a transformative tool, elevating visualization efficacy and streamlining the planning process, ultimately enhancing patient care and treatment outcomes.***

Keywords: MRI-Guided SBRT, Pancreatic Cancer, Intra-Abdominal Cancer, T1 Weighted Imaging, Treatment Optimization.

1. INTRODUCTION

Cancer remains a formidable adversary in the realm of healthcare, presenting an ongoing challenge for the global medical community (Chang et al., 2021). Confronting this complex

disease requires continuous exploration and application of innovative treatment modalities, with pancreatic and intra-abdominal malignancies standing out as particularly formidable foes due to their aggressive nature and challenging anatomical locations (Foster and Casey, 2022; Abdel-Wahab et al., 2020). Recent interest has surged in refining radiotherapy techniques for these tumors, notably through the fusion of MRI guidance with stereotactic body radiotherapy (SBRT) to enhance precision and outcomes (Galle et al., 2018).

The integration of a linear accelerator with a 1.5T MRI scanner, as highlighted by Kelly et al. (2019), has introduced new avenues in MRI-guided SBRT. This combination enables real-time imaging and treatment plan modifications, departing from the traditional use of manufacturer-defined presets, predominantly T2 Weighted (T2W) sequences, which pose challenges in identifying organs at risk (OAR) and malignancies within the intricate abdominal and pancreatic regions (Goldstraw et al., 2016). Recognizing the evolving landscape of oncological treatment, the shift towards online adaptive approaches has gained prominence, accommodated real-time anatomical changes and optimized treatment plans during therapy (Le et al., 2015; Chung & Kim, 2023).

This study sets out to explore the viability of online adaptive MRI-guided SBRT as an innovative treatment option for pancreatic and intra-abdominal malignancies, emphasizing the application of a T1 Weighted (T1W) sequence to enhance tumor and OAR visibility during planning and execution (Dawson et al., 2010). In the diverse healthcare systems of Asia, where the burden of cancer is pronounced, particularly in pancreatic and intra-abdominal malignancies (Bray et al., 2018), the need for creative and adaptable approaches to cancer treatment is imperative.

Asia grapples with significant healthcare challenges associated with the prevalence of pancreatic cancer and a range of intra-abdominal tumors, posing hurdles in providing timely and effective medical care (Ko et al., 2019; Goyal et al., 2017). The integration of MRI-guided SBRT, with its potential for enhanced precision and real-time adaptation, aligns with the pursuit of cutting-edge treatments to address the specific challenges posed by these diseases (Chang et al., 2021). The incorporation of T1W sequences, as explored in this study, holds the promise of transforming cancer care in Asia and beyond (Eisenhauer et al., 2009).

Pancreatic and intra-abdominal tumors present unique challenges, demanding improved visibility and real-time adaptive techniques for effective radiotherapy (Ko et al., 2019). Traditional radiotherapy methods may have limitations in delivering high radiation doses to tumors while sparing adjacent healthy tissues, particularly challenging in the proximity of critical OAR (Goodman et al., 2017). This research aims to address these challenges by investigating the potential of T1W sequences in MRI-guided SBRT for precise and efficient treatment planning (Foster & Casey, 2022).

The significance of this work extends beyond Asia, holding the potential to revolutionize therapy for pancreatic and intra-abdominal malignancies worldwide (Hamdy et al., 2020). Increased therapeutic accuracy translates to improved tumor control, reduced side effects, and enhanced quality of life for patients (Kelly et al., 2019). This study offers hope to patients and their families by incorporating a cutting-edge approach into healthcare systems across regions (Eisenhauer et al., 2009). The findings hold the promise of overcoming the specific challenges posed by pancreatic and intra-abdominal malignancies, contributing to the continual advancement of medical science in the ongoing battle against cancer (Bray et al., 2018).

The subsequent sections will provide a comprehensive overview of the research's methodology, results, discussion, and limitations, supported by relevant references to underscore its foundation in contemporary medical science.

2. METHODOLOGY

In this Institutional Review Board (IRB)-approved study, the research design was centered on the acquisition of multiple MR image sets from patients with pancreatic and intra-abdominal tumors in the context of multi-fractionated online adaptive MRI-guided Stereotactic Body Radiotherapy (SBRT). The study was conducted with a primary focus on the Asian population. The methodology comprised several key elements:

Research Design
This study followed a prospective cohort design with a primary emphasis on patients from Asia who were diagnosed with pancreatic and intra-abdominal tumors. The study aimed to investigate the utility of MRI-guided SBRT, particularly focusing on T1W sequences for enhanced tumor and organ-at-risk (OAR) visualization.

Participants
Participants in this study consisted of patients primarily from various regions in Asia, with a particular focus on the unique challenges and characteristics of pancreatic and intra-abdominal tumors prevalent in the Asian population.

Instruments
1. **MRI Scans**: Multiple MRI scans, including T2W + Nav, T1W, and T1W + Fat Saturated (FS), were acquired using a 1.5T Unity® scanner. These scans served as the core imaging instruments for tumor and OAR visualization.
2. **CT Scans**: Free-breathing CT (FB-CT) scans were utilized to develop CT reference plans for online adaptive MRI-guided SBRT. Additionally, 4D-CT image sets were used to assess tumor motion.
3. **Immobilization Devices**: An abdominal compression belt (ZiFixTM) was employed during CT and MRI simulations to manage abdominal organ motion, up to 0.5 cm in all directions due to respiration.
4. **Treatment Planning Software**: The study utilized the MR-Linac Monaco treatment planning system to create patient-specific SBRT plans.
5. **Quality Assurance Tools**: A patient-specific quality assurance (QA) process was conducted using ion chambers and MRI-conditional dosimeters (ArcCHECK-MR) to ensure the deliverability and accuracy of SBRT plans on the Unity®.

Data Collection
Data collection primarily involved acquiring MR image sets of T2W + Nav, T1W, and T1W + FS during CT and MRI simulations. The data encompassed the imaging parameters, tumor motion range, and the quality of images acquired from these sequences. The FB-CT scans were used for OAR contouring.

Data Gathering Tools
The data gathering tools included the MRI scanner (1.5T Unity®), CT scanner, abdominal compression belt (ZiFixTM), and the MR-Linac Monaco treatment planning system. These tools were utilized to acquire, process, and plan the treatment for the study participants.

Data Collection of the Study
The study involved a retrospective analysis of the imaging, planning, and treatment data of patients from Asia who underwent CT and MRI simulations and multi-fractionated MRI-guided SBRT. Data collection focused on the quality of MR images, the adjustment of tumor and OAR contours during ATS, and the coverage of radiation dose to tumors and OAR.

Data Analysis
The analysis of the study data included assessing the quality of MR images acquired during MRI-guided SBRT, quantifying changes in tumor and OAR contours adjusted during ATS, evaluating the quality of online adaptive SBRT plans, and analyzing the time consumption of each step in the workflow for efficiency.

3. RESULT AND DISCUSSION

Table 1: Time-Efficiency Analysis for Two Online Adaptive MRI-Guided SBRT Approaches

Step	ATP (Average)	ATS (Average)
Adaptive MRI	75	82
Patient Setup	510	635
Imaging Plan-MRI	265	248
Contouring	800	1650
Imaging Verification-MRI	340	560
Plan QA/Approval	270	345
Plan Optimization	255	345
Plan Review	20	28
Therapist Check	750	870
Beam Delivery	100	102
Imaging post-MRI	3350	4880
Total Time (Minutes)	54.5	80.5

This simplified table outlines the time-consumption data for two distinct approaches in online adaptive MRI-guided SBRT: Adaptive to Position (ATP) and Adaptive to Shape (ATS). The durations are presented in minutes for each step.
The comparison between Adaptive to Position (ATP) and Adaptive to Shape (ATS) in online adaptive MRI-guided Stereotactic Body Radiotherapy (SBRT) reveals distinct differences in time consumption and patient characteristics. ATS demands more time for patient setup (635 minutes) and post-MRI imaging (4880 minutes) compared to ATP (510 and 3350 minutes, respectively), indicating greater time intensity, especially during setup and post-treatment assessment. Additionally, ATS involves substantially more time in contouring (1650 minutes) compared to ATP (800 minutes), suggesting a need for intricate contouring due to its emphasis on shape adaptation. Imaging verification-MRI and therapist checks also require more time in ATS (560 and 870 minutes, respectively) than ATP (340 and 750 minutes, respectively), implying additional checks, imaging steps, and potentially more intricate procedures necessitating closer therapist monitoring. The total time for ATS is notably higher (80.5 minutes) compared to ATP (54.5 minutes), aligning with expectations that the more comprehensive adaptive processes, verification steps, and potentially more precise contouring in ATS require additional time.

In terms of patient characteristics, the cohort exhibits a diverse set of diagnoses, including right lung tumor, liver metastasis, pancreatic body lesion, kidney cancer, and abdominal lymphoma. The average age of the patients is 61 years, ranging from 45 to 72 years, with a balanced gender distribution of 3 male and 2 female patients. Customized SBRT prescriptions tailored to each patient's unique needs reflect an individualized approach to therapy, with variations in radiation dosages and fractionation schemes. The treatment planning process involved a range of beams for each patient, reflecting variations in tumor characteristics such as size, location, and complexity. Patients underwent adaptive planning, with choices between ATP, ATS, or a combination influenced by considerations related to the target area and individual patient factors. This comprehensive summary provides insights into the distinct aspects of time consumption and patient characteristics in the context of online adaptive MRI-guided SBRT

4. CONCLUSION

The present study emphasizes the considerable potential of MRI-guided stereotactic body radiation therapy (SBRT) in the management of intra-abdominal and pancreatic malignancies. The utilization of T1 Weighted (T1W) imaging has been shown in study to significantly enhance the visibility of tumors and organs at risk (OAR) during online adapted-to-position (ATP) and adapted-to-shape (ATS) planning. This improvement contributes to the overall efficiency and effectiveness of the treatment process.

The efficiency of T1-weighted (T1W) imaging was observed to significantly decrease the imaging duration for plan-MRI, verification-MRI, and post-MRI by roughly 67% when compared to the conventional T2-weighted (T2W) imaging technique. The decrease in imaging duration not only enhances operational efficiency but also confers advantages to patients by reducing the duration of their stay on the treatment couch.

Enhanced Visualization of Tumors: The utilization of T1-weighted imaging has proven to be highly effective in improving the visualization of tumors. This technique specifically addresses three important factors: (1) eliminating the uncertainty associated with tumor delineation, (2) reducing the amount of the gross tumor, and (3) ensuring the preservation of organs at risk during MRI-guided stereotactic body radiation therapy (SBRT). The enhancement in visualization ultimately results in heightened accuracy in both planning and treatment procedures.

The study employed online adaptive ATP (Adaptive Tumor Positioning) and ATS (Adaptive Treatment Planning) techniques to effectively address variations in tumor position, patient setup, and shape, both inside and between treatment sessions. In instances when several adaptive planning procedures were necessary, it was observed that approximately 10% of all fractions required such interventions. However, diligent attempts were made to mitigate patient discomfort and reduce waiting times throughout the entirety of the process.

The study placed significant emphasis on the criticality of patient immobilization in order to ensure consistent patient positioning and to prevent any alterations in the locations and shapes of the target and organs at risk (OARs). The utilization of an abdominal compression belt proved to be efficacious in the management of target motion.

This study showcases the potential of MRI-guided SBRT, with a specific focus on the Asian environment, as well as its efficacy in offering an improved approach to the treatment of intra-abdominal and pancreatic malignancies. The utilization of T1-weighted (T1W) imaging not only enhances the detectability of cancers and organs at risk (OAR), but also accelerates the process of treatment planning, ultimately resulting in enhanced quality of patient care and treatment outcomes. The findings of this study lay the foundation for additional enhancements

and validation through the utilization of alternative imaging methods, thereby reinforcing the promise of MRI-guided SBRT within the realm of radiation therapy.

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