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Systematic Review

Applicability of MRI-only technique in external beam radiotherapy: Dosimetric evaluation, IGRT, and quality assurance – A systematic review

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ABSTRACT

Introduction: Magnetic Resonance Imaging (MRI) provides superior soft tissue contrast compared to planning Computed Tomography (pCT). Although pCT remains the standard method in radiotherapy planning due to its provision of electron density information required for dose calculations, the MRI-only technique can replace pCT by generating synthetic CTs (sCTs) that supply the necessary density data.
Methods: A systematic literature review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The literature search was performed in April 2025 across the PubMed, Scopus, and Web of Science databases, applying inclusion and exclusion criteria defined using the PICOS model. The included studies were assessed using the "Appraising the Evidence: Reviewing Disparate Data Systematically" tool, and extracted data were synthesised in a narrative summary table.
Results: A total of 41 studies were included, covering different anatomical regions. The studies reported non-significant differences in dose-volume histograms (DVH) between sCT and CT. Gamma analysis conformity evaluations showed pass rates >87.4 %. The deviations across various image registrations remained <2 mm for translational displacements and <1.2° for rotations. Discrepancies between sCT-CT and sCT-Cone Beam CT were ≤1 %.
Conclusion: The MRI-only technique proved to be feasible for use in the central nervous system and pelvic regions, both in terms of dosimetry and image-guided verification. In head and neck oncology, the focus was exclusively on dosimetric planning. Further studies are required to validate and expand the applicability of this technique to other anatomical sites.
Implications for practice: These findings reinforce the applicability and versatility of the MRI-only approach across multiple anatomical regions and therapeutic contexts, highlighting its potential to improve patient comfort and streamline clinical workflows.

Introduction

Magnetic Resonance Imaging (MRI) is widely used in Radiotherapy (RT) planning due to its superior soft tissue contrast compared to Planning Computed Tomography (pCT).[1,2] This enhanced contrast enables more accurate delineation of the Gross Tumor Volume (GTV) and organs at risk (OARs), thereby reducing both interobserver and intraobserver variability.[1,2] Owning to these advantages, MRI is extensively employed in the diagnosis and therapeutic planning of various oncological conditions.[2,3] In

Abbreviations: cGAN, Conditional Generative Adversarial Network; CNN, Convolutional Neural Network; DSC, Dice Similarity Coefficient; DVH, Dose-Volume Histograms; GAN, Generative Adversarial Network; JI, Jaccard Index; MRCAT, Magnetic Resonance-based Attenuation Calculation; MRI, Magnetic Resonance Imaging; OI, Overlap Index; pCT, Planning Computed Tomography; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; rCT, Computed Tomography Registered with Magnetic Resonance; sCT, Synthetic Computed Tomography.

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both primary and secondary lesions of the central nervous system (CNS), MRI facilitates more accurate delineation of tumor boundaries, as well as identification of peritumoral edema.[2] In prostate tumors, it enhances the visualization of the prostate gland, rectum, and penile bulb, as well as characterization of intraprostatic lesions. This allows for overlays in areas with a high tumor burden.[2,4] The more precise definition of volumes provided by MRI contributes to more effective prescription of the dose to the prostate gland while limiting the dose to the rectum.[2] According to the literature, this imaging modality for planning may have applications in other pathologies also.[2,5]

Currently, CT simulation remains the standard in radiotherapy planning due to its ability to provide accurate information on tissue electronic density, which is essential for dosimetric calculation.[1,2] However, CT has limitations in delineating of the GTV and OARs, particularly in regions where soft tissue contrast is critical.[1,2] In some cases, inaccuracies in GTV definition may exceed the uncertainties associated with daily treatment setup.[2] To address these limitations, MRI has been incorporated into planning workflows via image registration with CT.[1,2,6] While this improves soft tissue visualization, it may introduce systematic errors due to image fusion algorithms and anatomical discrepancies between acquisitions.[1,2,6]

As an alternative, the MRI-only approach eliminates the need for CT image acquisition. In this workflow, a single MRI scan provides the anatomical data required for volume delineation. From these images, a synthetic CT (sCT) is generated to simulate Hounsfield Units (HU), enabling accurate dose calculations. This method not only reduces patient exposure to ionizing radiation from CT but also avoids registration-related errors between CT and MRI.[1,2]

sCTs can be generated using various methodologies. The voxel-based method estimates HU values for each MRI voxel based on signal intensity and anatomical context. The atlas-based method employs pre-registered MRI/CT image pairs to transfer HU values. The segmentation method involves delineating homogeneous tissue regions and assigning fixed HU values. Finally, hybrid approaches combine two or more of these techniques to enhance the accuracy and robustness of sCT generation.[1,2]

This review evaluates the feasibility of the MRI-only technique in external beam radiotherapy by identifying the anatomical regions where it demonstrates optimal performance. The review also examines dosimetric accuracy, quality assurance and verification methods, and the effects on Image-Guided Radiation Therapy (IGRT), comparing these outcomes with conventional two-dimensional (2D) and three-dimensional (3D) matching techniques.

Methodology

This study was conducted in accordance with the recommendations outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).[7] It was registered in the Open Science Framework (OSF) with the DOI identifier [Blinded for review] accessed on June 16, 2025. The registration includes comprehensive details of the systematic review protocol, thereby ensuring transparency and reproducibility. A structured literature search was performed across the PubMed, Web of Science, and Scopus databases, restricted to articles published in English. The search was conducted on 21st April 2025 and encompassed scientific publications from January 2010 to January 2025. The following keywords were used: radiation therapy, radiotherapy, MRI-only, MR-only, dosimetric, IGRT, and quality assurance.

To optimise the search strategy, Boolean operators (AND, OR, NOT) were applied in accordance with the specific configurations defined for each database. The search strings were constructed to combine three conceptual groups of keywords: the intervention ("MRI-only," "MR-only"), the application ("dosimetric," "IGRT," "quality assurance"), and the broader field ("radiation therapy," "radiotherapy"). These terms were systematically linked using Boolean operators to ensure a comprehensive search for all relevant literature, as summarised in Table 1.

Table 1
Identification of the search equations used in each database.

Databse	Equation
Pubmed	((radiotherapy[Title/Abstract]) OR ("radiation therapy"[Title/Abstract])) AND ("MRI-Only"[Title/Abstract] OR "MR-Only"[Title/Abstract]) NOT (brachytherapy[Title/Abstract]) NOT (proton[Title/Abstract]) NOT (MR-Linac[Title/Abstract]) AND ((IGRT[Title/Abstract]) OR (dosimetric[Title/Abstract]) OR (quality assurance [Title/Abstract]))
Web of Science	TS=(((radiotherapy) OR ("radiation therapy")) AND ("MRI-Only" OR "MR-Only") NOT (brachytherapy) NOT (proton) NOT (MR-Linac) AND ((IGRT) OR (Dosimetric) OR ("quality assurance")))
Scopus	((TITLE-ABS-KEY (radiotherapy) OR TITLE-ABS-KEY ("radiation therapy") AND TITLE-ABS-KEY ("mri only") OR TITLE-ABS-KEY ("mr only") AND TITLE-ABS-KEY (igrt) OR TITLE-ABS-KEY (dosimetric) OR TITLE-ABS-KEY ("quality assurance") AND NOT TITLE-ABS-KEY (brachytherapy) AND NOT TITLE-ABS-KEY (proton) AND NOT TITLE-ABS-KEY ("mri linac")) AND PUBYEAR >2009 AND PUBYEAR <2026)

The Population, Intervention, Comparison, Outcome, and Study Design (PICOS) framework[8] was employed to define the inclusion and exclusion criteria (see Table 2). Studies were included if they addressed the use of the MRI-only technique in radiotherapy, particularly those focusing on its application in dosimetry and dosimetric comparisons between synthetic CT (sCT) and conventional CT images. Also considered relevant were studies that applied the MRI-only technique in Image-Guided Radiation Therapy (IGRT), either by using sCT for registration with Cone Beam Computed Tomography (CBCT) or by generating Digital Reconstructed Radiography (DRR) from sCT for alignment with planar 2D-kV images. Additionally, studies evaluating the quality assurance of sCT were included.

Conversely, studies investigating the use of the MRI-only technique in proton therapy, brachytherapy, MRI-linac systems, or positron emission tomography (PET) for sCT generation were excluded.

Articles were selected using the online platform Rayyan,[9] which enables the import of records in RIS format and the automatic removal of duplicates. The initial screening of titles and abstracts was conducted independently by two reviewers (DP and LP), based on the predefined inclusion and exclusion criteria. Any disagreements were resolved by consensus or, when necessary, through the involvement of a third and fourth reviewer (JB and MC).

The methodological quality assessment of the included studies was aimed at estimating the strength and risk of bias of the evidence. The tool 'Appraising the Evidence: Reviewing Disparate Data Systematically' (Hawker et al., 2002)[10] was employed which encompasses nine assessment domains: summary and title; introduction and objectives; method and data; sampling; data analysis; ethics and biases; results; transferability/generalization; and implications/usefulness. Each domain was scored from 1 (very weak) to 4 (good), with a total score ranging from 9 to 36 points. Table 3 presents the results, and a detailed domain-specific assessment is provided in the appendix. The scores assigned independently were compared between reviewers (DP and LP), and any discrepancies were resolved by consensus with recourse to a third and fourth evaluator (JB and MC) whenever necessary (see Table 4).

Data extraction was performed through a full-text reading of the eligible studies. The following information was collected:

Table 2
PICOS, study inclusion and exclusion process.

Letter	Inclusion	Exclusion
P (Population)	Patients treated with external beam radiotherapy	MRI-linac Proton therapy Cyberknife
I (Intervention)	MRI-only technique	Generation of sCT using PET
C (Comparison)	Comparison of dosimetry between sCT and pCT. Comparison between the matching of sCT and CBCT Comparison of DRR matching of sCT with planar images (2D kV).	Different image processing methods to produce the sCT
O (Results)	Pathologies in which the use of the MRI-only technique was studied. Differences between dosimetry of sCT and pCT. Differences between 2D-2D and 3D-3D matching. Understanding the feasibility of sCT through quality controls	
S (Study design)	Interventional study Qualitative study Quantitative study Randomized controlled trial Quasi-experimental study Single-arm study	Review Meta-analysis Study protocol Oral presentation and poster abstracts

study identification (authors, year and country of publication), area of intervention, anatomical location, study aim(s), methodology used, sample characteristics, results, main conclusions, and overall evaluation, as summarised in Table 3.

Results

A bibliographic search of the PubMed, Web of Science, and Scopus databases yielded a total of 384 records. Following the removal of duplicates (n = 226), 158 unique articles remained. Based on the PICOS criteria, 83 studies were excluded after screening titles and abstracts, resulting in 75 articles selected for full-text assessment. Of these, 34 were excluded after full-text review, leading to the inclusion of 41 studies in the final systematic review. The detailed selection process is illustrated in Fig. 1.[7,8]

Of the 41 articles included, 19 focused on dosimetry, 14 analyzed both dosimetry and IGRT together; five dealt exclusively with IGRT; and three addressed quality assurance (QA). According to the objectives of this study, the results are presented below.

Dosimetric evaluation

The MRI-only technique was evaluated in the CNS, H&N, and pelvic regions by comparing sCT and pCT using parameters such as

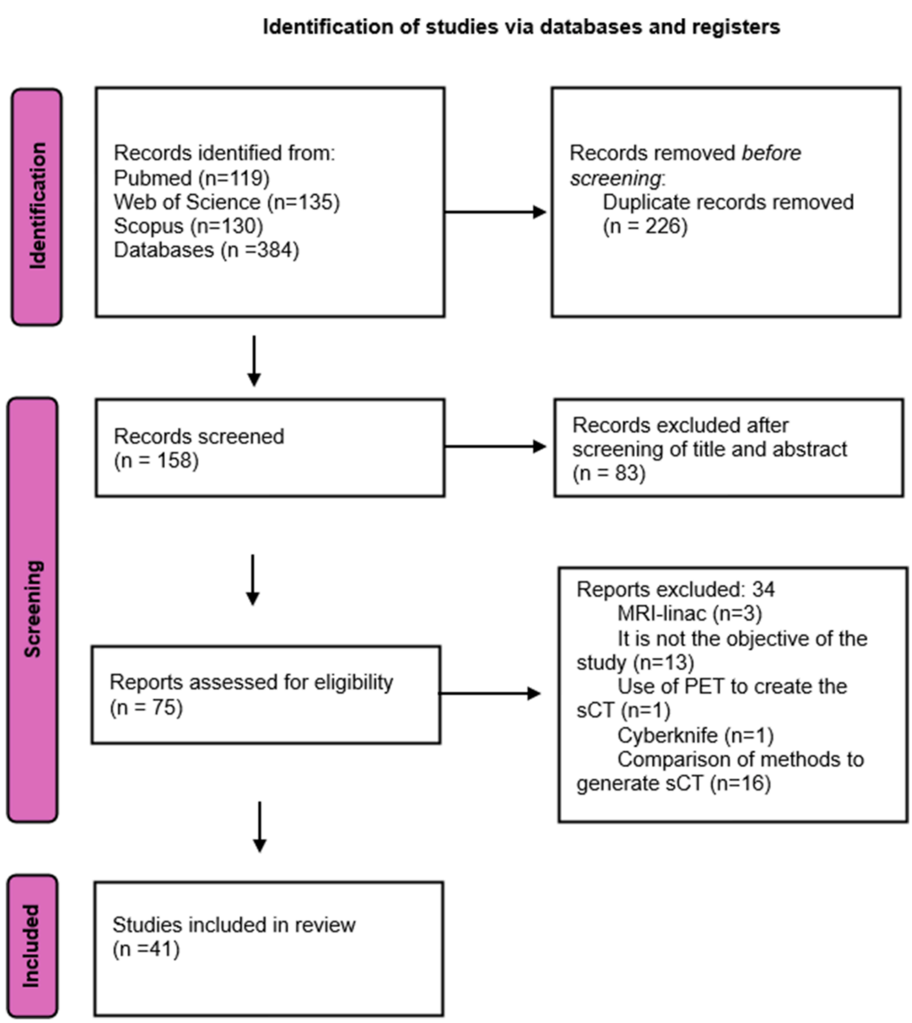

Figure 1. Selection process according to the PRISMA guidelines.

Table 3
Study of the characteristics of the selected articles.

Authors, Year of Publication and Country	Research Area	Anatomical Location	Objective	Study Type	Sample	Results	Main Conclusions	Article Assessment
Bird et al.,[11] 2023, United Kingdom and Sweden	Dosimetry	Pelvis (prostate, rectum, anal canal), central nervous system (CNS), head and neck (H&N), thorax, abdomen	Validate the dosimetric accuracy of sCT generated by Cycle-GAN compared to standard CT.	Retrospective study	Prostate -5 Anal canal- 16 Rectum- 28 CNS- 25 H&N- 30	Mean Absolute Errors (MAEs) of Hounsfiel Units (HU): 48.8- pelvis; 118-CNS T2 FLAIR; 116-CNS T1 Gadolinium; 124- H&N. Dose differences in PTV95 %: 0.2 % – pelvis (range: -0.9 %–1.0 %); 0.2 % – CNS (range: -0.7 %–0.9 %); 0.0 % – H&N (range: -0.5 %–0.4 %) Gamma analysis: 2 %/2 mm criterion: mean 99.6 % (minimum 95.2 %) 1 %/1 mm criterion: mean 97.3 % (minimum 80.1 %) All mean dose differences for OARs across all anatomical regions were ≤ ±0.5 %.	The sCTs generated by the Cycle-GAN algorithm showed sufficient dosimetric accuracy and anatomical fidelity for clinical use in radiotherapy planning	32
O'Connor et al.,[12] 2022, Australia	Dosimetry	Pelvis (rectum, anal canal, gynecological)	Validate the use of a hybrid sCT generation technique, using both female and male atlases for the treatment of pelvic tumors.	Prospective study	40	The mean percentage dose difference at the ICRU reference point between the CT and sCT treatment plans was -0.4 % for the male cohort and -0.3 % for the female cohort. The average gamma pass rate in the 3D gamma analysis using criteria of 3 %/2 mm, 2 %/2 mm, and 1 %/1 mm was above 93.4 % for both. The MAE in HU was 59.1 ± 7.2 HU for the male cohort and 53.3 ± 8.9 HU for the female cohort.	The MRI-only method is clinically feasible for radiotherapy planning in pelvic patients of both sexes.	36
Dinkla et al.,[13] 2018, Netherlands	Dosimetry	CNS	Evaluate whether synthetic CT images generated by a dilated Convolutional Neural Network (CNN) allow accurate dose calculations for central nervous system tumor treatment.	Retrospective study	52	The geometric accuracy of the sCT images was high, with a mean surface distance between the CT and sCT body contours of 0.75 ± 0.2 mm Dosimetric analysis showed mean deviations of 0.00 % ± 0.02 % for the dose within the body contours and -0.13 % ± 0.39 % within the PTV. The 3D gamma analysis pass rates were above 95 % for the 3 %/3 mm criterion.	The sCT generated by the dilated CNN enabled accurate dose calculations.	34
Jabbarpour et al.,[14] 2022, Switzerland	Dosimetry	CNS	Develop an unsupervised approach based on Cycle Generative Adversarial Network (CycleGAN) to generate sCT using multicenter data	Retrospective study	189 (Tests were performed in 39 patients: 17-T1 and 22-T2)	The gamma analysis with acceptance criteria of 3 %/3 mm, 2 %/2 mm, and 1 %/1 mm resulted in 98.96 % ± 1.1 %, 95 % ± 3.68 %, and 90.1 % ± 6.05 %, respectively. The differences in DVHs between CT and sCT images remained within 2 %	The sCT generated by CycleGAN was able to handle heterogeneous multicenter datasets.	34
Yip et al.,[15] 2024, China	Dosimetry	CNS	Perform a clinical validation of the MRI-based Attenuation Calculation algorithm (MRCAT) to assess its potential for implementation in the MRI-only workflow.	Prospective study	33 (18 treated with IMRT/VMAT and 15 treated with SRS)	IMRT/VMAT – The mean error (ME) was 23.42 ± 1.05 HU, the MAE was 38.03 ± 1.42 HU, and the root mean square error (RMSE) was 89.09 ± 6.65 HU. SRS – The ME was 28.39 ± 3.17 HU, the MAE was 52.36 ± 2.63 HU, and the RMSE was 108.38 ± 12.23 HU. There were no significant differences in	The sCT is valid for clinical use in radiotherapy planning of CNS tumors with IMRT/VMAT and SRS	34

						DVH parameters related to PTV coverage between the plans. Gamma pass rates were:3 %/3 mm: 99.92 % for IMRT/VMAT and 99.86 % for SRS2 %/2 mm: 99.42 % for IMRT/VMAT and 99.52 % for SRS1 %/1 mm: 96.47 % for IMRT/VMAT and 97.57 % for SRS		
Ilamurugu et al.,[16] 2018, India	Dosimetry	CNS	Compare the dose calculation accuracy of the MRI-only technique for hypofractionated stereotactic radiotherapy (HSRT).	Retrospective study	18	The ME in Dmax and D0.5cc of the brainstem between CT and sCT without optimization was 2.49 % and 1.45 %, respectively. When compared to the sCT plans with optimization, the variations were -1.56 % for Dmax and -1.97 % for D0.5cc, indicating a reduction in differences with the use of optimization.	There is no evidence of differences between the CT and sCT plans.	36
Singhrao et al.,[17] 2023, USA	Dosimetry	H&N	Investigate whether the errors in assigning HU to voxels in sCT images lead to dosimetric errors in treatment plans.	Retrospective study	14	Significant differences in HU values were observed between sCT and CT images for air and bone, but not for soft tissues. The structures showing the largest HU differences (> 80 HU) between sCT and CT are small structures and/or those located near interfaces between tissue, bone, and air. Despite these HU differences, treatment plans recalculated on sCT images showed gamma pass rates of 95.5 % $\pm$ 2 % (3 %/3 mm) and 92.7 % $\pm$ 2.1 % (2 %/2 mm), with the largest average differences in DVHs for PTVs and OARs being below 3 %.	The differences in HU values between sCT and CT did not translate into a significant reduction in gamma analysis pass rates or differences in mean dose values for the PTV and OARs	32
Emin et al.,[18] 2022, Sweden	Dosimetry	CNS	Describe the clinical implementation process of a commercial sCT solution for treatment planning of CNS.	Retrospective and prospective study	First phase- 112 (30 for dosimetric analysis) Second phase- 48 (30 for dosimetric analysis)	The mean dose difference for the CTV and PTV was within $\pm$0.7 %. The mean dose differences for the OARs were within $\pm$1.3 % for the plans calculated on images used for both cohorts. The gamma pass rates for the brain structure using criteria of 1 %/1 mm, 2 %/2 mm, and 3 %/3 mm were 93.6 %/ 99.8 %/100 % and 96.6 %/99.9 %/100 % for the setup and validation cohorts, respectively.	The dosimetric results in the setup and validation phases confirmed the equivalence of sCT compared to CT, enabling confident integration of the MRI-only workflow.	36
Bird et al.,[19] 2020, United Kingdom	Dosimetry	Anal canal and rectum	Develop and validate a conditional GAN (cGAN) model based on deep learning to generate sTC.	Prospective study	Rectum- 73 Anal canal- 17	Rectum – Mean dose difference in PTV D95 % of 0.1 % (ranging from -0.5 % to 0.7 %) with a standard deviation (SD) of 0.3 % Anal canal – Mean dose difference in PTV D95 % of 0.1 % (ranging from -0.2 % to 0.5 %) with a SD of 0.2 % Gamma pass rates were: 3 %/3 mm: 100 % for rectum and 99.9 % for anal canal 2 %/2 mm: 99.8 % for rectum and 99.7 % for anal canal 1 %/1 mm: 99.5 % for rectum and 99.4 % for anal canal	The sCT is dosimetrically accurate.	36

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Table 3 (*continued*)

Authors, Year of Publication and Country	Research Area	Anatomical Location	Objective	Study Type	Sample	Results	Main Conclusions	Article Assessment
						For OARs, the mean dose difference was 0.1 %		
Dinkla et al.,[20] 2019, Netherlands	Dosimetry	H&N	Evaluate the dosimetric accuracy of sCT generated by a patch-based 3D CNN for H&N radiotherapy.	Retrospective study	34	The MAE of the sCT was 75 ± 9 HU. The ME was 9 ± 11 HU. Dosimetric analysis showed mean deviations of -0.03 % ± 0.05 % for the dose within the body region and -0.07 % ± 0.22 % within the volume receiving >90 % dose. On average, the 3D gamma analysis pass rates were: (2 %/2 mm) – 95.6 % ± 2.9 % (3 %/3 mm) – 98.7 % ± 1.4 %.	The proposed sCT enabled accurate dose calculations for radiotherapy treatment planning of H&N tumors.	36
Wyatt et al.,[21] 2023- United Kingdom, Germany, Switzerland, Netherlands, and Hungary.	Dosimetry	Pelvis	Accurately evaluate the dose calculation of a sCT algorithm with Deep Learning in the pelvic region.	Prospective study	Prostate-10 Rectum- 4 Anal canal- 6	Artificial PTVs: the mean dose difference for PTVs D98 % was ≤0.5 %. Clinical cases: the mean dose differences for PTV D98 % was ≤0.4 %. Gamma analysis 2 %/2 mm prostate: 99.0 ± 0.2 % (97.4 %, 99.9 %); Rectum: 98.7 ± 0.5 % (97.6 %, 99.5 %); Anal canal: 98.3 ± 0.3 % (97.2 %, 99.4 %). Gamma analysis 1 %/1 mm: Prostate: 98.0 ± 0.4 % (95.6 %, 99.4 %); Rectum: 96.5 ± 0.8 % (94.9 %, 98.0 %); Anal canal: 95.4 ± 0.6 % (93.8 %, 98.3 %). Deformable registration improved the results, reducing the range of D98 % dose differences to [-1.4 %, 0.3 %] and [-0.9 %, 0.4 %] for the comprehensive and clinical evaluations, respectively.	The sCT is sufficiently accurate for clinical use in all pelvic sites	32
Burgos et al.,[22] 2017 - United Kingdom and Netherlands	Dosimetry	Prostate	Evaluate a segmentation and sCT synthesis method for the MRI-Only technique.	Retrospective study	15	The MAE between CT and sCT was on average 45.7 ± 4.6 HU, with an ME of -1.6 ± 7.7 HU. The average differences in doses calculated using CT and sCT were: 0.14 % for PTV D98 %; Between -0.14 % and 0.05 % for PTV, bladder, rectum, and femoral heads for Dmean and D2%.	The proposed method has the potential to eliminate the need for performing a CT for dosimetric planning	33
Lui et al.,[23] 2021 - China	Dosimetry	CNS	Investigate the dosimetric accuracy of sCT.	Retrospective observational study.	20	The average gamma analysis pass rate (1 %/1 mm) was 92.2 %. The mean dose difference in PTV D95 and Dmax was -0.1 % and -0.3 %, respectively. For the OARs, the mean dose difference was within 0.2 Gy, and no statistically significant differences were found.	This method is accurate for dosimetric calculation	33
Bourbonne et al.,[24] 2021 - France	Dosimetry	CNS	Evaluate the equivalence of GAN-generated sCT for stereotactic radiotherapy (SRT) planning in the CNS.	Retrospective study	189	Average RMSE values were 175.50 HU ± 63.15 for the bone structure and 13.54 ± 1.96 for the soft tissue structure. The DRRs from sCT and CT are quite comparable: Average RMSE value of 86.16 HU ± 19.80 and mean RMSE of 80.30 HU.	The sCT generated by GAN is equivalent to CT for SRT planning in the CNS.	33

						Gamma analysis: The pass rate threshold to be considered successful was set at 95 %. Local gamma analysis (1 %/1 mm) was 87.4 %; (2 %/2 mm) was 99.1 %; and (2 %/1 mm) was 97.99 %. Global gamma analysis: 99.2 % for 1 %/1 mm DVH: No significant differences were found for OARs and PTV.		
Tang et al.,[25] 2021 - China	Dosimetry	CNS	Develop a CNN to generate sCT and evaluate dosimetric accuracy.	Retrospective study	37	The MAE between sCT and CT was 60.52 ± 13.32 HU. The average gamma analysis pass rates using 3 %/3 mm and 2 %/2 mm criteria were 99.76 % and 97.25 %, respectively. For the DVH parameters, both for the PTV and the OARs, no significant differences were found between plans based on sCT and CT.	The developed GAN model can perform sCT with high dosimetric accuracy.	32
Andreasen et al.,[26] 2016 - Denmark	Dosimetry	Prostate	Evaluate the robustness of a patch-based approach for generating sCT of the male pelvic region.	Retrospective study	10	In the DVH, this approach demonstrated deviations of: ±0.04 % for the PTV ±0.2 % for the femur ±0.4 % for the rectum The V65/75 % of the rectum showed some variations, which are attributed to the presence of air.	This approach can generate an sCT with dosimetric accuracy.	31
Wang et al.,[27] 2019 - USA	Dosimetry	CNS	Investigate the dosimetric calculation accuracy in SRS of an sCT generated by a machine learning method.	Retrospective study	14	CT and sCT showed identical quality, with very similar contrast and details. The differences in DVH between sCT and CT were: PTV was <0.6 % OARs was 0.05 %, not significant The average gamma analysis for 3 %/3 mm was 99 %, ranging from 97.5 % to 100 %.	Dosimetric planning using sCT is sufficiently accurate to replace CT in SRS treatment.	32
Greer et al.,[28] 2019, Australia	Dosimetry	Prostate	Investigate the feasibility of implementing planning with the MRI-only technique	Prospective study	30	The mean dose difference at the isocenter between calculations performed on sCT and CT was -0.04 ± 0.93 %. Gamma analysis (2 %/2 mm) averaged 99.7 ± 0.5 %. Gamma analysis (3 %/3 mm) averaged 100 % ± 0.1 %.	MRI-only workflows can be implemented safely and accurately in a multicenter environment.	36
Christiansen et al.,[29] 2017, Denmark	Dosimetry	Prostate	Evaluate the feasibility of an MRI-only workflow and the validity of dose calculations for prostate cancer treatment.	Retrospective study	30	The average gamma analysis pass rates at 1 %/1 mm and 2 %/2 mm were 100 % for most of the evaluated structures. In the 1 %/1 mm gamma analysis, some structures showed pass rates below 95 %, which originated from the presence of air in the rectum.	The MRI-only workflow is clinically feasible.	36
Kemppainen et al.,[30] 2019, Finland	Dosimetry and IGRT	Pelvis (prostate, rectal, and gynecological)	Evaluate the clinical feasibility of using sTC images derived from MRI images for external radiotherapy planning in different pelvic tumors.	Prospective study	Definitive prostate - 15 Postoperative prostate - 15 Regional pelvic lymph nodes - 15	The average difference in the relative dose in the PTV between sTC and TC was less than 0.2 % (±0.4 %) across the different cancer groups. The average approval rates in the gamma analysis were above 95 % using the 2 %/2 mm criterion. The mean deviation in patient	The use of sTC for dose calculation and patient positioning verification for different types of pelvic tumors was accurate for clinical use.	36

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Table 3 (*continued*)

Authors, Year of Publication and Country	Research Area	Anatomical Location	Objective	Study Type	Sample	Results	Main Conclusions	Article Assessment
					Rectum - 15 Gynecological - 15	positioning between TC-DRR and sTC-DRR was less than 0.3 mm (±1.4 mm) in all directions. The registrations between sTC and CBCT performed comparably to those between TC and CBCT.		
Maspero et al.,[31] 2018, The Netherlands	Dosimetry and IGRT	Rectum	Investigate whether a certified commercial sTC solution for prostate cancer patients could also be used for patients with rectal cancer.	Experimental study	20	Average dose deviations of -0.3 ± 0.2 % from the prescribed dose were obtained between the CT and sCT plans, within a threshold of 90 % of the prescribed dose. The mean pass rate for gamma analysis at 2 %/2 mm was 95.2 ± 4.0 % within this dose threshold. Mean differences in translations and rotations (CBCT to CT vs. CBCT to sCT): <1 mm in translations and <0.5° in rotations. Exception: Mean systematic deviation of 0.7 ± 0.6 mm in the Anterior-posterior (AP) direction.	The dose calculations and the accuracy of sTC positioning verification were clinically feasible for the treatment of patients with rectal cancer.	35
Liu et al.,[32] 2021, USA	Dosimetry and IGRT	CNS	To evaluate the dosimetric and IGRT performance of an sTC generated by GAN in the CNS.	Retrospective study	12 (6 stereotactic radiosurgery (SRS) and 6 conventional radiotherapy)	SRS – The average approval rate in gamma analysis at 1 %/1 mm – (99.5 ± 0.7 %) and at 2 %/2 mm – (100 ± 0.0 %). Conventional brain radiotherapy – The average approval rate in gamma analysis at 1 %/1 mm – (98.7 ± 1.8 %) and at 2 %/2 mm – (99.9 ± 0.2 %). The mean differences in HDV were ≤0.10 ± 0.04 Gy in the PTV and ≤0.13 ± 0.04 Gy in the OARs. The mean differences in CBCT-sTC and kV-sTC DRR registrations, compared to CT, were <0.2 mm and <0.5 mm, respectively.	The sTC demonstrated excellent performance for dosimetric and IGRT criteria, for both conventional treatment and SRS	35
Ranta et al.,[33] 2023, Finland	Dosimetry and IGRT	CNS	Evaluate the clinical feasibility of a commercial MRI-only based radiotherapy treatment planning method for the CNS, focusing on dosimetric accuracy and patient positioning verification.	Retrospective study	50 (25 – gliomas; 25 – brain metastases (BM))	Glioma – The mean dose difference in the PTV was 0.1 %, and for the OARs it was 0.6 %. BM – The mean dose difference in the PTV was 0.5 %, and for the OARs it was 1.0 %. Gamma analysis approval rate 2 %/2 mm–99.2 % for BM and 98.0 % for gliomas. Gamma analysis approval rate 1 %/1 mm–95.2 % for BM and 82.1 % for gliomas. Using CBCT, the mean distance differences were <1.0 mm in all Cartesian directions between CT and sCT positioning.	The accuracy of dose calculation and patient positioning using the MRI-only method demonstrated clinical feasibility for CNS radiotherapy planning.	36
Posiewnik et al.,[34] 2022, polónia	Dosimetry and IGRT	Prostate	Validate the dosimetric and geometric accuracy of the MRI-only	Retrospective study	10	Approval rate in gamma analysis 1 %/1 mm - 97 % with an SD of 0.7 % Approval rate in gamma analysis 2 %/	The MRI-only method demonstrated geometric and dosimetric accuracy	33

			technique for prostate cancer			2 mm - 99 % with an SD of 0.4 % All CTV volumes delineated on CT were larger than CTV volumes delineated on MRI ($p = 0.005$).	comparable to the conventional method.	
Tyagi et al.,[35] 2016, USA	Dosimetry and IGRT	Prostate	Evaluate the dosimetric and workflow accuracy of a commercial sTC software for clinical use in prostate cancer treatment.	Prospective study	25	Average dose difference less than 0.5 % between CT and sCT plans for all structures. Average geometric distortion less than 1 mm in the body and less than 0.5 mm in the prostate. Average localization differences less than 1 mm between DRRs from CT and sCT, and between CBCT and sCT.	The MRI-only workflow was successfully validated	35
Kazemifar et al.,[36] 2019, USA	Dosimetry and IGRT	CNS	Evaluate the dosimetric accuracy of sTC images generated by deep learning for MRI-only in the CNS.	Retrospective study	77	The mean MAE was 47.2 $\pm$ 11.0 HU. The morphological similarity between the CT and the sCT was high, with a mean Dice coefficient of 80 % $\pm$ 6 % for bone tissue and 70 % $\pm$ 7 % for air. The mean percentage differences between the doses calculated with CT and sCT were statistically insignificant and less than 1 % for all DVH parameters. Likewise, the mean difference in monitor units (MU) between the CT and sCT plans was less than 1 % and not statistically significant.	The proposed method has great potential to be successfully used in a clinical workflow for MRI-only treatment planning in the CNS.	33
Liu et al.,[37] 2019, USA	Dosimetry and IGRT	CNS	Develop and assess the feasibility of deep learning approaches for treatment planning with MRI-Only.	Retrospective study	40- training sample 10– Evaluation sample	The absolute percentage differences in dosimetric parameters between sCT and CT were 0.24 % $\pm$ 0.46 % for the PTV, 1.39 % $\pm$ 1.31 % for the maximum dose, and 0.27 % $\pm$ 0.79 % for the PTV V95 %. No significant difference was found for the PTV volume ($P = 0.50$), maximum dose ($P = 0.83$), and V95 % ($P = 0.19$) between sCT and CT. sCT shows Dice coefficients for air of 0.95 $\pm$ 0.01, soft tissue of 0.94 $\pm$ 0.02, and bone of 0.85 $\pm$ 0.02, and a MAE of 75 $\pm$ 23 HU compared to CT.	The sTC provides a viable alternative for radiotherapy planning with MRI-only.	36
Lerner et al.,[38] 2021, Sweden	Dosimetry and IGRT	CNS	Validate sTC images generated by the CNN to enable radiotherapy planning with MRI-only.	Prospective study	20	The MAE of sTC was 62.2 $\pm$ 4.1 HU. The mean differences in absorbed dose between sTC and CT were <0.2 % for the PTV and OARs. The average approval rate for the global gamma analysis (1 %/1 mm) for all patients was 100.0 $\pm$ 0.0 % within the PTV and 99.1 $\pm$ 0.6 % for the entire dose distribution. No clinically relevant deviations were found in the image registrations of CBCT-sTC vs CBCT-CT.	The results were consistent between sCT and CT images in terms of dosimetry and geometric evaluation, for patients both with and without anatomical changes.	36
Siversson et al.,[39] 2015 - Sweden	Dosimetry and IGRT	Prostate	Compare the dose calculations between sCTs generated by the Statistical Decomposition Algorithm (SDA) and CT	Single-arm study	10	The mean HU difference was 36.5 $\pm$ 4.1 HU between the sCT and the rCT (CT registered to the MR). The difference in absorbed dose for the target was 0.0 % $\pm$ 0.2 % between the sCT and the rCT, and -0.3 % $\pm$ 0.3 % between the CT and the rCT.	The sCT generated by SDA is comparable to CT and can be used clinically.	31

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Table 3 (*continued*)

Authors, Year of Publication and Country	Research Area	Anatomical Location	Objective	Study Type	Sample	Results	Main Conclusions	Article Assessment
			in the male pelvic region.			Gamma analysis approval rate gamma (2 %/1 mm) was 99.9 % for sCT vs rCT, and 90.3 % for CT vs rCT. The difference in mean absorbed dose in the PTV was 0.0 % ± 0.2 % between the sCT and rCT. The mean difference in absorbed dose between the sCT and the rCT was 0.0 % ± 0.3 %, 0.1 % ± 0.3 %, and −0.1 % ± 0.3 % for the bladder, rectum, and femoral heads, respectively.		
Masitho et al.,[40] 2022 - Germany	Dosimetry and IGRT	CNS	To evaluate the feasibility of a commercial AI algorithm for generating an sCT for dosimetric calculation and daily patient positioning using 2D kV images.	Retrospective study	26	The MAE between sCT and CT was 135.8 ± 12.9 HU The differences between the CT and sCT plans were dosimetrically acceptable. The mean difference in CI was 0.3 % The mean differences in table rotation for pitch, roll, and yaw were -0.4°/-0.1°/-0.4°. The mean absolute differences in displacement and rotation after subtracting the systematic error were <1 mm and <1°. For the PTV, the mean dose difference between the sCT and CT for D50 was -0.2 %–0.2 %. For the OARs, the mean dose difference between the sCT and CT for D50 was -0.6 %–1.6 %.	The sTC provided results comparable to CT for dosimetric calculation and daily patient positioning using 2D kV images.	33
Yu et al.,[41] 2021 - USA	Dosimetry and IGRT	Pelvis	Validate a software tool for the generation of sCT images	Quantitative study	Prostate – 77 Rectum – 43 Gynecological – 27	The average dose difference between the sCT and CT plans was less than 1 % for all structures. The MAE between sCT and CT was 120.9 ± 15.4 HU for bone, 33.4 ± 4.1 HU for soft tissue, and 38.8 ± 4.0 HU for the total body contour. The mean value of the pearson correlation coefficient between the DRRs generated by CT and sCT was 0.975. The mean deviations between CT and sCT as a reference for matching by bone for CBCT were (LR, AP, SI) = (0.19 ± 0.35, 0.14 ± 0.60, 0.44 ± 0.54) mm.	The software generated an sTC and DRRs accurately, allowing for dosimetric planning.	32
Persson et al.,[42] 2020 - Sweden	Dosimetry and IGRT	Prostate	Present and evaluate the feasibility of a new MRI-Only workflow for the treatment of prostate cancer.	Retrospective study	40	The HDV had a maximum deviation of less than 2 % after correction for rectal gas. All gamma analyses (3 %/3 mm; 3 %/2 mm; 2 %/2 mm; 2 %/1 mm) were above 98 % The differences between the sTC-CBCT and TC-CBCT registrations, as well as	The study demonstrates the feasibility of a new workflow for the MRI-Only technique for prostate cancer treatment	35

						between CT and sTC, were generally <2 mm for most patients		
Lerner et al.,[43] 2022, Sweden	Dosimetry and IGRT	CNS	Investigate the clinical implementation of MRI-only for the treatment of CNS tumors.	Prospective study	21	The dose differences in the PTV were within ±1 % for all patients. The approval rates for the gamma 2 %/2 mm analysis were above 99 %. Patient positioning using CBCT images was within ±1 mm for registrations with sCT compared to CT.	The clinical implementation of sTC demonstrated high dosimetric and geometric accuracy.	36
Edmund et al.,[44] 2021, Denmark	IGRT	Prostate	Evaluate the feasibility and accuracy of CBCT for IGRT in MRI-only.	Retrospective study	10	The average difference between the sCT and CT registration for IGRT with CBCT had mean deviations of up to 1.5 mm and 1.2°, with a maximum standard deviation (SD) of 4 mm However, significant differences were observed in some directions, especially in the craniocaudal (CC) direction and pitch. (1° with an SD (1°–2°)	The MRI-only approach with sTC is feasible for prostate IGRT.	36
Kan et al.,[45] 2019, Japan	IGRT	Prostate	Evaluate the accuracy of IGRT using sCT with CBCT for patient positioning in MRI-only workflows.	Retrospective study	15	The absolute registration errors of CBCT, compared to pCT, were 0.34 ± 0.50 mm (lateral), 1.3 ± 1.3 mm (longitudinal), and 1.1 ± 0.99 mm (vertical).	The sTC matching is insufficient for use in patients with prostate cancer without implanted fiducial markers.	36
Morris et al.,[46] 2019, USA	IGRT	CNS	Compare the geometric equivalence between CT-DRRs and sCT-DRRs, and to quantify the performance of sCT in IGRT.	Retrospective study	10	The geometric agreement between DRRs generated from sCTs and conventional CTs was excellent, with overlap index (OI) values > 0.95, Dice Similarity Coefficient (DSC) > 0.95, and Jaccard index (JI) > 0.95 in both AP and lateral positions. The mean absolute 3D displacement was <2 mm in 77.7 ± 10.8 % and 76.5 ± 7.2 % of the CT and sCT records, respectively.	The geometry of the DRRs-sCT was robust and showed excellent matching between the DRRs from the sCT and the CT. Differences were observed between the CT and sCT registrations, but the results were not clinically significant.	35
Price et al.,[47] 2017, USA	IGRT	CNS	Evaluate the accuracy and reliability of using sCT images for IGRT.	Retrospective study	12	The mean differences in registration shifts between sCT and CT were <0.8 mm in all axes for both planar and volumetric registrations.	The registrations of planar and volumetric images that used sCT images were compatible with the registrations that used CT images.	36
Edmund et al.,[48] 2015, Denmark	IGRT	CNS	Evaluate the clinical feasibility of plan verification and CBCT-guided positioning for MRI-only radiotherapy and to assess the accuracy of sCT.	Experimental study	6	No significant differences were observed in the matching between CBCT and sTC, with maximum deviations <1 mm and 1°. The MAE in HU was 184 ± 34 between sTC-CT and 299 ± 34 between sTC-CBCT, with this difference being statistically significant ($p < 0.01$). For the relative electron density (RED), the values were similar between sTC-CT (0.108 ± 0.025) and sTC-CBCT.	The sTC has proven to be clinically viable for verifying patient positioning and administering treatment with adequate precision.	33
Palmér et al.,[49] 2017- Sweden	QA	Prostate	Develop a quality assurance (QA) procedure for sCT using CBCT in an MRI-only workflow for prostate cancer patients.	Single-arm study	10	The SD ranged from 5.9 to 40 HU for tissues with RED from 0.2 to 1.7. Lower variation of 60 HU between CBCT and sCT. The dose differences between sCT and CT, and between sCT and CBCT, were ≤1.0 % for all HDV metrics.	It is possible to use CBCT as QA for sCT.The dose calculations between sCT and CBCT showed a difference in absorbed dose within clinically acceptable criteria.	33

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Table 3 (*continued*)

Authors, Year of Publication and Country	Research Area	Anatomical Location	Objective	Study Type	Sample	Results	Main Conclusions	Article Assessment
Wyatt et al.,[50] 2021-United Kingdom	QA	Prostate	Evaluate the use of CBCT as a QA method for dosimetric accuracy in prostate cancer treatment using the MRI-only technique.	Prospective study	49 (20 underwent CT; 29 did not undergo CT)	The mean dose difference between sTC and CBCT in both Cohorts was -0.6 ± 0.1 %, with a range from -2.3 % to 2.3 %. 47 out of 49 patients were within the range of [-2 %, 1 %] The dose difference at the isocenter between sTC-CBCT was systematically lower than sTC-CT by -0.7 ± 0.6 % The mean rate of the gamma analysis for sTC-CBCT (2 %/2 mm) was 96.1 ± 0.4 % (ranging from 85.4 % to 99.7 %)	The use of CBCT from the first fraction may be a promising method for QA of the sTC dose accuracy in the MRI-Only technique.	33
Harten et al.,[51] 2019 - Netherlands	QA	CNS	Develop and evaluate an automatic online QA method for sCT in the MRI-Only technique.	Quantitative experimental study	52 – with and without contrast 34 – healthy subjects (OASIS)	Mean uncertainty in the test sets: Non-contrast MRI: 135 ± 8.3 HU Contrast-enhanced MRI: 144 ± 9.6 HU OASIS: 202 ± 13.7 HU The mean uncertainty in the contrast-enhanced MRI and OASIS sets was significantly higher ($p < 0.05$) than in the non-contrast set.	The method developed to estimate sTC uncertainty is effective and can be valuable for automatic QA in MRI-Only workflows.	30

AP – Antero-Posterior; BM – Brain Metastases; CBCT – Cone Beam Computed Tomography; CC – Cranio-Caudal; CI – Conformity Index; cGAN – Conditional Generative Adversarial Network; CNN – Convolutional Neural Networks; CTV – Clinical Target Volume; DAS – Statistical Decomposition Algorithm; Dcc – Dose in Cubic Centimeters; Dmax – Maximum Dose; Dmean – Mean Dose; DP – Standard Deviation; DRR – Digitally Reconstructed Radiography; DSC – Dice Similarity Coefficient; ED – Left-Right; GAN – Generative Adversarial Network; Gy – Gray; DVH – Dose-Volume Histogram; HSRT – Hypofractionated Stereotactic Radiotherapy; ICRU – International Commission on Radiation Units and Measurements; IGRT – Image-Guided Radiotherapy; IMRT – Intensity-Modulated Radiotherapy; JI – Jaccard Index; kV – Kilovoltage; MAE – Mean Absolute Error; ME – Mean Error; MRCAT – Magnetic Resonance-based Attenuation Calculation; OARs – Organs at Risk; OI – Overlap Index; ORL – Otorhinolaryngology; PTV – Planning Target Volume; QA – Quality Assurance; RED – Relative Electron Density; RM – Magnetic Resonance; RMSE – Root Mean Square Error; rCT – Computed Tomography Registered with Magnetic Resonance; SI – Superior-Inferior; sCT – Synthetic Computed Tomography; CNS – Central Nervous System; SRS – Stereotactic Radiosurgery; SRT – Stereotactic Radiotherapy; CT – Computed Tomography; HU – Hounsfield Units; MU – Monitor Units; VMAT – Volumetric Modulated Arc Therapy.

Table 4
Quality assessment of 41 articles with the tool Hawker et al. (2002).

Authors, publication data, country	Summary and title	Introduction and Objectives	Method and data	Sampling	Data analysis	Ethics and biases	Results	Transferability/ generalization	Implications/ usefulness
Bird et al., 2023 – United Kingdom and Sweden	Good	Fair	Good	Fair	Good	Fair	Good	Fair	Good
Kemppainen et al., 2019, Finland	Good	Good	Good	Good	Good	Good	Good	Good	Good
Maspero et al., 2018, Netherlands	Good	Good	Good	Good	Good	Fair	Good	Good	Good
Liu et al., 2021, USA	Good	Good	Good	Good	Good	Good	Good	Fair	Good
Jens et al., 2021, Denmark	Good	Good	Good	Good	Good	Good	Good	Good	Good
Kan et al., 2019, Japan	Good	Good	Good	Good	Good	Good	Good	Good	Good
Ranta et al., 2023, Finland	Good	Good	Good	Good	Good	Good	Good	Good	Good
Posiewnik, 2022, Poland	Good	Good	Good	Good	Good	Very poor	Good	Good	Good
Christiansen et al., 2017, Denmark	Good	Good	Good	Good	Good	Good	Good	Good	Good
O'Connor et al., 2022, Australia	Good	Good	Good	Good	Good	Good	Good	Good	Good
Tyagi et al., 2016, USA	Good	Good	Good	Good	Good	Fair	Good	Good	Good
Dinkla et al., 2018, Netherlands	Good	Good	Good	Good	Good	Poor	Good	Good	Good
Jabbarpour et al., 2022, Switzerland	Good	Good	Good	Good	Good	Poor	Good	Good	Good
Kazemifar et al., 2019, USA	Good	Good	Good	Good	Good	Very Poor	Good	Good	Good
Yip et al., 2024, China	Good	Good	Good	Good	Good	Poor	Good	Good	Good
Ilamurugu et al., 2018, India	Good	Good	Good	Good	Good	Good	Good	Good	Good
Singhrao et al., 2023, USA	Good	Good	Good	Fair	Good	Poor	Good	Fair	Good
Emin et al., 2022, Sweden	Good	Good	Good	Good	Good	Good	Good	Good	Good
Bird et al., 2020, United Kingdom	Good	Good	Good	Good	Good	Good	Good	Good	Good
Morris et al., 2019, USA	Good	Good	Good	Good	Good	Fair	Good	Good	Good
Price et al., 2017, USA	Good	Good	Good	Good	Good	Good	Good	Good	Good
Liu et al., 2019, USA	Good	Good	Good	Good	Good	Good	Good	Good	Good
Lerner et al., 2021, Sweden	Good	Good	Good	Good	Good	Good	Good	Good	Good
Dinkla et al., 2019, Netherlands	Good	Good	Good	Good	Good	Good	Good	Good	Good
Edmund et al., 2015, Denmark	Good	Good	Good	Fair	Good	Fair	Good	Fair	Good
Palmér et al., 2017- Sweden	Good	Good	Good	Fair	Good	Fair	Good	Fair	Good
Wyatt et al., 2023- United Kingdom, Germany, Switzerland, Netherlands and Hungary	Good	Good	Good	Fair	Good	Poor	Good	Fair	Good
Burgos et al., 2017 - Reino Unido e países Baixos	Good	Good	Good	Fair	Good	Fair	Good	Fair	Good
Lui et al., 2021 - Hong Kong	Good	Good	Good	Fair	Good	Fair	Good	Fair	Good
Bourbonne et al., 2021 – France	Good	Good	Good	Fair	Good	Fair	Good	Fair	Good
Siversson et al., 2015 - Sweden	Good	Good	Good	Fair	Good	Very poor	Good	Fair	Good
Tang et al., 2021 - China	Good	Good	Good	Fair	Good	Very poor	Good	Good	Good
Masitho et al., 2022 - Germany	Good	Good	Good	Fair	Good	Fair	Good	Fair	Good
Andreasen et al., 2016 - Denmark	Good	Good	Good	Fair	Good	Very poor	Good	Fair	Good
Yu et al., 2023 - USA	Good	Good	Good	Fair	Good	Very poor	Good	Good	Good
Wang et al., 2019 - USA	Good	Good	Good	Fair	Good	Poor	Good	Fair	Good
Wyaat et al.,2021- United Kingdom	Good	Good	Good	Fair	Good	Fair	Good	Fair	Good
Persson et al., 2020 - Sweden	Good	Good	Good	Good	Good	Fair	Good	Good	Good
Greer et al., 2019, Australia	Good	Good	Good	Good	Good	Good	Good	Good	Good
Lerner et al., 2022, Sweden	Good	Good	Good	Good	Good	Good	Good	Good	Good
Harten et al., 2019 - Netherlands	Good	Good	Good	Fair	Fair	Very poor	Good	Fair	Good

Scores: Very Poor (1); Poor (2); Fair (3); Good (4).

the Mean Absolute Error (MAE) of Hounsfield Units (HU), dose-volume histograms (DVH), and gamma analysis.

In the CNS, studies primarily focused on IMRT/VMAT, with some also investigating SRS[15,27,32] and SRT.[24] Reported MAEs for IMRT/VMAT treatments ranged from 38.03 ± 1.42 HU to 135.8 ± 12.9 HU.[11,15,25,36–38,40,41] DVH variations were generally below 2 % in most studies.[13–16,18,23–25,27,32,33,36–38,40,43] Gamma analysis revealed pass rates above 82.1 % for all acceptance criteria, with this result associated with the 1 %/1 mm criterion.[11,13–15,18,23–25,27,32,33,38,43] Ranta et al.[33] investigated the application of this technique for gliomas and brain metastases and observed a difference between the two pathologies in gamma analysis with 1 %/1 mm criteria: 95.2 % for brain metastases and 82.1 % for gliomas. This discrepancy may be due to the smaller PTV volume of metastases in the study, resulting in lower performance for gliomas when applying stricter criteria 1 %/1 mm.[33]

In stereotactic radiosurgery (SRS) applications, gamma analysis pass rates for all acceptance criteria showed results above 97.5 %, associated with the 3 %/3 mm criteria. DVH differences for PTV were <0.6 % and 0.05 % for OARs.[15,27,32]

In fractionated stereotactic radiotherapy (SRT), values of 87.4 %, 99.1 %, and 97.99 % were observed for the 1 %/1 mm, 2 %/2 mm, and 2 %/1 mm criteria, respectively. The overall average pass rate was 99.2 % (1 %/1 mm). To consider the *gamma* analysis acceptable, a minimum acceptance criterion was set, requiring at least 95 % in the analysis result.[24]

The H&N region is a complex region, representing a challenge for the application of the *MRI-Only* technique, due to the proximity of bone structures and air cavities, which makes it difficult for systems to accurately assign Hus.[17] The MAEs observed in the comparison between sCT and CT ranged from 75 ± 9 HU to 124 HU.[11,17,20] In one study, the largest differences exceeded 80 HU in small structures and/or structures close together among tissue, bone, and air.[17] Although some variations in HU were observed, the evaluation of DVHs showed only small differences between CT and sCT.[17] In the PTV95 % parameter, a mean difference of 0.0 % was recorded (range: -0.5 %–0.4 %).[11] In another study, the differences between the PTV and the OARs were less than 3 %.[17] In the *gamma* analysis, the lowest value for the 3 %/3 mm criterion was 95.5 % ± 2.0 %, and for the 2 %/2 mm criterion it was 92.7 % ± 2.1 %. The highest value was 98.7 % ± 1.4 % for the 3 %/3 mm criterion, and 95.6 % ± 2.9 % for the 2 %/2 mm criterion.[11,17,20]

Several studies have been conducted on the *MRI-only* technique in the pelvic region, with the majority focusing on the prostate area. However, more recent studies have also explored its applications in the rectum, anal canal, and gynecological region. The MAEs ranged from 45.7 ± 4.6 HU to 59.1 ± 7.2 HU.[11,12,22] One study identified specific MAEs of 120.9 ± 15.4 HU for bone and 33.4 ± 4.1 HU for soft tissue.[41] The study with the largest difference in DVH reported a result of <2 %[42] and, in most studies, dose deviations in the PTV, OARs, and isocenter were less than 0.5 %.[11,19,21,22,26,28,30,39] A maximum deviation of 1.2 % in the PTV was reported by Persson et al.[42] In some cases, dose variations were attributed to the presence of air in the rectum[26,42]; after correction (assigning 0 HU), improvement was observed.[42] Gamma analysis showed approval rates above 93.4 % for all criteria.[11,12,19,21,28–31,34,39,42]

Regarding sex-based differences, one study reported MAEs of 59.1 ± 7.2 HU in males and 53.3 ± 8.9 HU in females, with dose differences at the ICRU reference point of 0.4 % and 0.3 %, respectively. Three-dimensional gamma analysis showed pass rates above 93.4 % for the 3 %/2 mm, 2 %/2 mm, and 1 %/1 mm criteria.[12]

IGRT evaluation

IGRT was evaluated in the CNS and pelvic regions by comparing sCT and CT. Analyses were conducted for mean translational deviations and rotations, Overlap Index (OI), Dice Similarity Coefficient (DSC), Jaccard Index (JI), and mean Pearson correlation coefficients.

In the CNS, several studies have assessed the geometric accuracy and agreement between traditional methods based on CT and the new sCT-based workflows. A key finding was the high fidelity of tissue boundaries in sCT, which is critical for accurate image matching from a front-end perspective. Equivalence was confirmed between DRRs generated from both sCT and CT, with mean deviations of less than 1.0 mm in translational displacements and less than 1.0° in rotations.[31,39,46] These values remained consistent in CBCT-sCT and CBCT-CT registrations, in all evaluated directions.[31,32,37,42,46,47] Morris et al.[45] found good geometric agreement between sCT and CT with the DRRs, reporting an OI, DSC, and JI all above 0.95 in both Antero-Posterior (AP) and lateral positions. This high similarity indicates that the tissue contours are well-represented in the sCT, which facilitates accurate image alignment with CBCT on the user interface. Additionally, they reported a mean absolute 3D displacement of less than 2 mm in 77.7 ± 10.8 % and 76.5 ± 7.2 % of the CT-DRR and sCT-DRR registrations, respectively.[46] Masitho et al.[40] demonstrated that, with better immobilization during MRI acquisition, systematic differences in the Pitch, Roll, and Yaw directions were reduced from -1.9°, 0.3°, and 0.3°, respectively, to -0.4°, -0.1°, and 0.4°.

The pelvic region has been extensively studied for its application in MRI-only techniques. To assess its applicability in IGRT, the possibility of performing this technique using 2D and 3D images was evaluated. In the 2D images, the DRRs from CT and sCT were compared, and the matching differences between them were <2 mm.[30,35] Additionally, an average Pearson correlation coefficient of 0.975 was determined.[41] This correlation coefficient further supports the excellent representation of tissue boundaries in sCT, crucial for accurate image matching. The use of CBCT was also evaluated, and the comparison between sCT and CBCT revealed maximum deviations of up to 2 mm translational and 1.2° rotational.[30,31,35,41,42,44] The concordance of tissue contours between sCT and CBCT, as evidenced by the small deviations, is a significant factor in facilitating accurate image alignment in the clinical workflow. Maspero et al.[31] also reported a mean systematic deviation of 0.7 ± 0.6 mm in the AP direction. Edmund et al.[44] recorded greater differences in the craniocaudal (CC) direction and pitch, possibly due to the relatively short longitudinal field of view of MRI.

Quality control evaluation

Quality control assessments were conducted in the CNS and pelvic regions using MAE of HU, gamma analysis, and DVH metrics.

In the CNS, a QA system using artificial intelligence was tested for sCTs generated via convolutional neural networks (CNNs), yielding a mean absolute error of the HU of 135 ± 8.3 HU.[51]

Palmér et al.[49] evaluated the stability of CBCT in the pelvic region using a phantom and found an SD that ranged from 5.9 to 40 HU in all tissues with a relative electron density (RED) of 0.2–1.7. They noted that the variation in HU between CT and CBCT was less than 60 HU, indicating that CBCT provides similar information for tissue attenuation.[49] The dose variation between sCT-CT and sCT-CBCT was ≤1.0 % for all DVH metrics,[49] and Wyatt et al.[50] reported an average difference of -0.6 ± 0.1 %, with a range of -2.3 %–2.3 %, and an average sCT-CBCT gamma analysis pass rate (2 %/2 mm) of 96.1 ± 0.4 %, within a range of 85.4 %–99.7 %. The studies showed that CBCT can be used as QA for prostate sCT, with the caveat that CBCT systems need to be calibrated and that results vary depending on the system used in each center.[49,50]

Discussion

In recent years, numerous studies have explored the applicability of *MRI-only* techniques across various anatomical regions. Despite the growing body of literature, the limited sample sizes in individual studies constrain the generalisability of their findings. Nevertheless, five multicentre studies have contributed to broader applicability by mitigating local biases and enabling more robust conclusions.[14,19,21,28,41]

Dosimetric evaluation studies have focused mainly on the CNS, head and neck, and pelvic regions. Regarding the CNS, the results suggest that this technique offers dosimetric accuracy appropriate to the clinical context, both in IMRT/VMAT and SRS and SRT.[11,13–16,18,23–25,27,32,33,36–38,40,43] One study confirmed that the model supported multicenter datasets.[14] Bourbonne et al.[24] estimated that a sample size of 3146 patients would be required to achieve statistical significance, whereas the largest study included only 189 patients.[14,24] Thus, small sample sizes remain a recurring limitation. Nonetheless, the results are consistent with existing literature.[52]

The number of available studies in the H&N region is still limited, which does not allow for definitive conclusions. Nevertheless, the data suggest that the technique may be applied in this region, which is in accordance with the literature.[52,53]

In pelvic radiotherapy, accurate dose delivery is crucial. Several studies have shown a consensus regarding the dosimetric accuracy of the MRI-only technique for this region, encompassing the prostate, rectum, and anal canal. In this review, we chose to group together studies relating to different sites, namely the prostate,[22,26,28,29,34,35,39,42,44,45] rectum[19,31] and anal canal,[19] as some authors refer to these areas, in general, as the pelvis.[11,12,21,30,41] However, a major challenge in using MRI for treatment planning in the pelvis areas is image distortion. This distortion negatively impacts the accurate delineation of the GTV and the CTV, which, in turn, compromises the treatment plan and the precise delivery of the radiation dose. The extent of this distortion is not uniform; it's minimal near the isocenter, often at a sub-millimeter scale, but it increases significantly as you move toward the edges of the scanner bore. This issue is especially problematic for pelvic radiotherapy due to the large field of view (FOV) required to image the entire area.[28,29,34,35]

Of the selected articles, four multicenter studies provided more robust results.[19,21,28,41] One of them employed the LME model *(Linear Mixed Effects)* to assess the impact of the hospital, sex, and anatomical location.[19] This model determined a 95 % confidence interval for the dose difference between CT and sCT, ranging from 0.0 % to 0.2 %, revealing no significant differences in dose.[19] The studies agree with the literature, as demonstrated in an article that also shows that the use of *MRI-only* in the pelvis can be performed with minimal dosimetric impact.[54]

In the evaluation of the IGRT technique using the *MRI-only* approach, a limited set of publications was observed compared to the field of dosimetry, with existing research focusing mainly on the CNS[32,33,36–38,40,43,46–48] and the pelvic region.[30,31,34,35,39,41,42,44,45]

In the CNS, all studies demonstrated the feasibility of the technique, with differences in 2D-2D and 3D-3D *matching* between sCT and CT being non-significant.

In the pelvis, the results also indicate the appropriateness of the technique, with a multicenter study[41] further highlighting its applicability. However, Kan et al.[45] reported that this technique was not viable in the absence of fiducial markers. The use of traditional gold fiducial markers in pelvic IGRT presents a significant challenge in MRI-only workflows, as they appear as local signal voids on MR images, hindering their visibility in sCT images. This limitation has prompted the exploration of alternative solutions, such as novel AI-based detection algorithms and the use of artificial fiducial markers integrated into the sCT image.[45] For instance, Bird et al.[55] observed minimal systematic variations, reinforcing the consistency of the data.

Quality control is crucial to ensure the reliability and reproducibility of processes and is therefore the subject of ongoing research. The integration of quality assurance (QA) into the clinical workflow is paramount for validating the accuracy of synthetic CT images and ensuring dosimetric safety.[51] In the context of the CNS, the QA study proposes an AI-based approach aimed at streamlining the workflow. While the results appear promising, the sample used was not sufficiently representative, making further studies necessary to validate its large-scale applicability.[51]

In the pelvic region, two studies have shown that CBCT can be used as a QA for the *MRI-only* technique; however, given the small number of cases analyzed, further research with more representative samples is imperative to validate these findings.[49,50]

Conclusion

The MRI-only technique has gained increasing attention and clinical application, particularly in the CNS and pelvic regions. Although the number of studies in the H&N region remains limited, the availability of commercial algorithms for sCT generation in this area underscores its potential. Among the included studies, it was not possible to evaluate the technique's applicability in other anatomical regions such as the breast, lungs, and abdomen. Furthermore, the lack of data on IGRT applications in the H&N region and the limited number of studies addressing IGRT and QA represent notable limitations. Another key limitation is the small sample size across studies, which affects representativeness and raises concerns about the generalisability of conclusions.

The clinical applicability of MRI-only workflows has been consistently demonstrated in the treatment of CNS and pelvic malignancies across all evaluated domains —dosimetry, IGRT, and QA. While the technique shows promise in the H&N region, further validation is required. Across the reviewed studies, differences between sCT and CT were generally non-significant, indicating comparable accuracy, with only one exception noted in IGRT for the pelvic region, where the absence of fiducial markers compromised viability. In the CNS, the technique proved effective across IMRT, VMAT, SRS, and SRT modalities, highlighting its versatility.

Future research should focus on studies with more representative cohorts, exploration of additional anatomical regions, assessment of the dosimetric impact of air reclassification in various cavities, and evaluation of the economic feasibility of MRI-only workflows.

Ethics approval and consent to participate

Not applicable.

This manuscript is a comprehensive literature review that does not involve the collection of primary data from human participants or animals. Therefore, ethical approval or consent was not required.

Availability of data

Data for this study was taken from the PubMed accessible at https://pubmed.ncbi.nlm.nih.gov; Web of Science accessible at https://www.webofscience.com/wos/woscc/basic-search and Scopus accessible at https://www.scopus.com/pages/home?display=basic#basic.

Author contributions

DP: Conceptualisation, Methodology, Investigation, Writing - Original Draft, Visualisation.

LP: Conceptualisation, Methodology, Investigation, Writing - Original Draft, Visualisation.

JB: Validation, Writing - Review & Editing, Visualisation, Supervision.

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Generative AI use

During the preparation of this work, the author(s) used Paperpal for writing. After using this tool/service, the author(s) reviewed and edited the content as needed and took (s) full responsibility for the content of the publication.

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