

Review

Are Water-Based Algorithms Still Adequate for Dose Calculation in Modern HDR Interventional Radiotherapy? A Review with Special Focus on 3D-Printed Applicators and Heterogeneous Materials

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Simple Summary

High-dose-rate interventional radiotherapy (HDR IRT) depends on accurate dose calculations. The traditional TG-43 method assumes all tissues are like water, but this can lead to inaccuracies in modern treatments involving tissue heterogeneities and 3D-printed applicators. This narrative review of 35 studies found that TG-43 often overestimates dose, while model-based dose calculation algorithms (MBDCAs) provide more accurate results. Although TG-43 remains widely used, model-based methods are increasingly important for improving treatment accuracy, especially in complex and personalized HDR IRT applications.

Abstract

Background: High-dose-rate interventional radiotherapy (HDR IRT) relies on accurate dose calculations to ensure safe and effective treatment. The AAPM TG-43 formalism, based on homogeneous water assumptions, has long been the clinical standard, but the growing use of patient-specific applicators and heterogeneous materials challenges its accuracy. **Materials and Methods:** A literature narrative review was performed using PubMed and Scopus to identify studies comparing TG-43 and model-based dose calculation algorithms (MBDCAs), including deterministic methods (ACE, Acuros BV) and Monte Carlo simulations. Thirty-five studies were selected and qualitatively analyzed. **Results:** TG-43 yielded higher dose compared with MBDCAs, particularly in the presence of tissue heterogeneities, air gaps, shielding materials, and limited scatter conditions. Differences ranged from 2 to 5% in relatively homogeneous settings to more than 10–20% in complex geometries such as superficial mould treatments and head-and-neck IRT. Model-based approaches showed better agreement with Monte Carlo simulations and experimental measurements, especially in contact HDR IRT and applications involving 3D-printed applicators. **Conclusion:** While



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TG-43 remains clinically established and widely used, its limitations are increasingly evident in modern personalized HDR IRT. Model-based dose calculation algorithms provide greater dosimetric accuracy and should be progressively integrated into clinical practice, particularly in treatments involving significant heterogeneities.

Keywords: brachytherapy; interventional radiotherapy; algorithm

1. Introduction

Interventional Radiotherapy (IRT, Modern Brachytherapy) is a form of radiotherapy in which radioactive sources are placed in close proximity to or within the target volume, enabling the delivery of highly conformal radiation doses while limiting irradiation of surrounding healthy tissues. This treatment modality is widely used for several oncological indications, including gynecological, prostate, breast, skin, and head and neck cancers. In particular, high-dose-rate (HDR) IRT has become increasingly adopted in modern clinical practice due to its flexibility in treatment planning, the possibility of optimizing dwell times and positions, and its compatibility with image-guided procedures, as well as for logistical advantages, improved patient management, and radiation protection benefits compared to low-dose-rate (LDR) IRT. One of the key components of IRT treatment planning is the accurate calculation of the dose distribution delivered by radioactive sources within complex anatomical environments.

For several decades, dose calculations in IRT treatment planning systems have primarily relied on the formalism described in the AAPM Task Group 43 (TG-43) report [1]. This approach is based on a water-based dose formalism in which the radioactive source is assumed to be placed at the center of a sufficiently large homogeneous water phantom, conventionally a sphere with a diameter of about 40 cm, to ensure full scatter conditions and approximate an unbounded medium. Dose distributions are calculated using pre-tabulated dosimetric source-specific parameters derived from measurements and Monte Carlo (MC) simulations in water, including the dose-rate constant, radial dose function, and anisotropy function. In this framework, patient-specific heterogeneities, applicator materials, and variations in scatter conditions are not explicitly modeled. The TG-43 formalism has been widely adopted due to its simplicity, robustness, and computational efficiency, allowing fast and stable dose calculations in routine clinical workflows. However, the simplifying assumptions underlying this approach may introduce inaccuracies in several clinically relevant scenarios, particularly when tissue heterogeneities, air cavities, shielding materials, or complex applicator geometries are present. This limitation becomes especially relevant in modern contact IRT, where materials with different physical densities may be intentionally introduced for clinical purposes, such as acting as a bolus to improve surface dose distribution, providing shielding to protect nearby organs at risk, or enabling the fabrication of patient-specific applicators that improve conformity to curved anatomical surfaces and reduce air gaps. Several studies have reported measurable differences between TG-43 and model-based dose calculation algorithms, particularly in the presence of heterogeneities such as air cavities, shielding materials, or limited scatter conditions, with deviations that may exceed 10% in specific scenarios [2,3]. Similar effects, often more pronounced due to lower photon energies, have also been described in LDR IRT, highlighting the role of radiation transport physics for dose calculation accuracy [4].

To overcome these limitations, more advanced computational approaches have been developed to incorporate patient-specific anatomical and material information into dose calculations. Model-Based Dose Calculation Algorithms (MBDCAs) represent a class of

computational methods designed to explicitly simulate radiation transport in heterogeneous media. Unlike TG-43 calculations, these algorithms as described in the TG-186 report account for variations in tissue density, elemental composition, and applicator materials by using patient-specific imaging data, typically derived from computed tomography scans (CT) [2]. It should be noted that, unlike TG-43, TG-186 does not define a single formalism, but rather provides a comprehensive framework describing the available model-based dose calculation approaches and their clinical implementation [5,6]. Depending on the computational strategy adopted, model-based algorithms can be broadly classified into deterministic and stochastic approaches. Deterministic algorithms solve the radiation transport equation using numerical methods, whereas stochastic approaches rely on MC techniques that simulate the probabilistic interactions of radiation particles with matter.

Among the deterministic algorithms implemented in commercial IRT treatment planning systems, two approaches are particularly relevant (Figure 1). The Advanced Collapsed Cone Engine (ACE), implemented in the Oncentra Brachy (Elekta AB, Stockholm, Sweden) treatment planning system, is based on a collapsed-cone superposition method that estimates dose deposition by modeling primary photon transport and scattered radiation using pre-calculated energy deposition kernels. In this approach, dose contributions from primary photons are convolved with scatter kernels to approximate the spatial distribution of deposited energy. Another widely used deterministic algorithm is Acuros BV, implemented in the BrachyVision (Siemens Healthineers AG, Erlangen, Germany) treatment planning system. This method relies on a grid-based Boltzmann solver (GBBS) that directly solves the linear Boltzmann transport equation on a spatial grid, allowing explicit modeling of photon transport and interactions in heterogeneous media characterized by different densities and elemental compositions. In addition to deterministic approaches, stochastic methods based on MC simulations represent the most physically accurate strategy for radiation transport modeling. By simulating individual particle histories and their probabilistic interactions with matter, MC methods provide highly accurate dose calculations and are commonly considered the reference standard for benchmarking IRT dose calculation algorithms, as schematically illustrated in Figure 1.

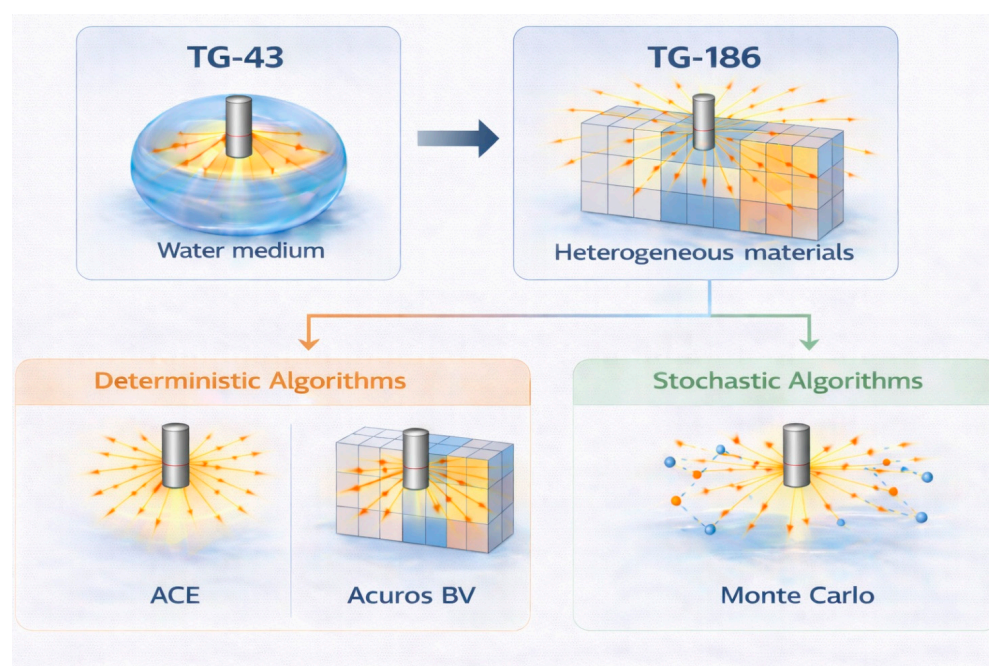


Figure 1. Conceptual schematic of the main dose calculation algorithms used in HDR IRT treatment planning systems for clinical and research purposes.

The TG-186 report describes a range of model-based dose calculation approaches that allow the explicit inclusion of tissue heterogeneities, applicator materials, shielding components, and finite patient boundaries in the radiation transport model, resulting in a more realistic representation of dose deposition in clinical scenarios. The importance of implementing MBDCAs in IRT treatment planning has become even more relevant in recent years due to technological advances in applicator design and manufacturing. In particular, recent studies have increasingly reported the use of patient-specific applicators produced using additive manufacturing techniques. Three-dimensional (3D) printing technologies enable the fabrication of customized applicators tailored to patient anatomy and specific clinical requirements, improving applicator positioning and enhancing treatment accuracy [7–9].

In this framework, materials with different physical densities and atomic compositions can be intentionally selected to fulfill several clinical purposes. Tissue-equivalent materials may be used as a bolus to improve surface dose distribution, whereas high-density materials can be incorporated as shielding elements to reduce dose to nearby organs at risk. In addition, patient-specific applicators can be designed to closely conform to irregular and curved anatomical surfaces, reducing air gaps and improving contact between the applicator and the skin. This aspect is particularly relevant in contact IRT, where the curvature of anatomical regions, such as the ear, nasal dorsum, or periocular area, may significantly influence dose distribution and target coverage [10]. The ability of 3D printing to reproduce patient-specific geometries therefore represents an important advantage for optimizing treatment in these challenging locations. However, the use of materials with different densities and compositions introduces heterogeneities in the radiation transport environment that are not accounted for by conventional water-based dose calculation approaches. Consequently, dose calculations based on homogeneous water assumptions may not accurately represent the actual dose distribution when such devices are used. In this context, MBDCAs provide a significant advantage, as they allow the explicit inclusion of material properties and density variations within the computational model, enabling more realistic and patient-specific dose estimations.

In addition to clinical applications, the need for accurate dose calculation methods is also increasingly relevant in translational research settings. In recent years, HDR IRT has been progressively employed in experimental platforms for radiobiological investigations, including *in vitro* irradiation systems designed to reproduce clinically relevant dose delivery conditions. In these experimental setups, precise characterization of the delivered dose distribution is essential to correctly interpret biological responses and correlate them with radiation exposure. However, such platforms often involve complex geometries, small irradiation volumes, and heterogeneous materials that may significantly deviate from the homogeneous water conditions assumed in the TG-43 formalism. In light of this, the use of more advanced computational approaches, such as model-based dose calculation algorithms or Monte Carlo simulations, becomes particularly important to ensure accurate and reproducible dosimetric characterization of experimental irradiation systems [11].

Despite the increasing availability of MBDCAs in modern treatment planning systems, their clinical implementation, validation, and application across different IRT sites remain areas of ongoing investigation [3,4,12]. Differences in algorithmic approaches, computational performance, and dosimetric accuracy continue to be explored in the scientific literature. Therefore, a comprehensive overview of the current developments in MBDCAs in IRT is valuable to better understand their methodological foundations, validation strategies, and potential clinical impact.

In recent years, several review articles have addressed the development and implementation of MBDCAs in IRT. Previous reviews have primarily focused on the physical principles of MBDCAs and their dosimetric performance compared with the TG-43 for-

malism, highlighting the improved accuracy achievable when tissue heterogeneities and applicator materials are explicitly modeled. Other studies have reviewed the clinical implementation and commissioning aspects of TG-186-based algorithms in treatment planning systems, emphasizing the importance of appropriate validation procedures and benchmarking against MC simulations. However, despite these comprehensive reviews, limited attention has been devoted to the implications of MBDCAs in the context of rapidly evolving technologies in HDR IRT, such as patient-specific 3D-printed applicators, heterogeneous materials, shielding devices, and emerging translational applications. In addition, emerging approaches have recently demonstrated the feasibility of applying MBDCAs using mobile cone-beam CT (CBCT) systems instead of conventional CT imaging, potentially enabling adaptive and patient-specific treatment planning directly within the IRT suite [13]. These developments introduce increasingly heterogeneous treatment environments that may challenge the assumptions underlying conventional water-based dose calculation approaches [14,15]. Therefore, the aim of the present narrative review is not to systematically reassess the evidence on MBDCAs, but rather to provide an updated perspective on their role in modern HDR IRT, with particular emphasis on technological innovations that are progressively reshaping dose calculation requirements, including additive manufacturing and heterogeneous treatment environments.

2. Materials and Methods

A literature search was performed to identify studies investigating the application of MBDCA in high-dose-rate (HDR) IRT. The search was conducted in February 2026 using the Scopus and PubMed databases, employing combinations of the keywords “HDR brachytherapy” and “MBDCA”, as well as the extended terms “model-based dose calculation algorithms” and “TG-186 formalism”, always in combination with “brachytherapy” or “HDR brachytherapy”. Inclusion criteria were studies investigating dose calculation algorithms in HDR brachytherapy, including clinical, phantom, simulation, or methodological studies. Studies focusing on low-dose-rate (LDR) brachytherapy, as well as those not directly addressing dose calculation approaches or not related to HDR IRT, were excluded.

Titles and abstracts of the retrieved records were screened to assess their relevance to the topic of model-based dose calculation in IRT. Articles identified as reviews, conference papers, or those without accessible full-text versions were excluded from further evaluation. The search strategy was subsequently expanded using additional combinations of the extended terminology to ensure the inclusion of relevant publications. After merging the results obtained from the different keyword combinations, removing duplicate records, and excluding studies without available full text, 35 papers remained and were included in the qualitative analysis of this narrative review.

For each included study, relevant information was extracted and systematically analyzed. In particular, the following characteristics were considered: study design, anatomical site or clinical application, dose calculation approach, study model, potential use of 3D-printing technologies, and the primary aim of the study. These parameters were used to qualitatively synthesize the literature and provide an overview of the methodological approaches, clinical contexts, and technological developments related to MBDCAs in HDR IRT.

3. Results

The literature analysis included studies investigating the development, validation, and clinical implementation of MBDCAs in HDR IRT. The main characteristics of the included studies are summarized in Table 1 for QA and dosimetric purposes and in Table 2 for patient studies, while the distribution of dose calculation comparisons across

clinical applications is illustrated in Figure 2. Notably, only 9% of the included studies involved the use of 3D-printed manufactured devices or applicators. The analyzed publications comprised methodological developments, phantom and experimental validations, in-silico investigations, and retrospective clinical studies performed on patient cohorts, and they covered a broad spectrum of HDR IRT applications. Based on the treatment technique or anatomical site, the studies were categorized into gynecological IRT, contact IRT, interstitial IRT (excluding gynecological cases), and quality assurance or phantom investigations, together with a smaller subset of methodological developments. Contact HDR IRT represented the most frequently investigated clinical scenario. Gynecological IRT constituted another substantial portion of the literature, primarily involving intracavitary or hybrid intracavitary–interstitial treatments for cervical cancer. Interstitial HDR IRT studies included breast implants, prostate treatments, and CT-guided liver IRT, while several publications focused on algorithm commissioning procedures, benchmarking datasets, and experimental validation platforms.

Table 1. Overview of the studies included in the literature review on dose calculation algorithms in HDR IRT for quality assurance (QA) or dosimetric studies.

	Application	Dose Calculation Approach	Study Model	Primary Aim
Siebert et al., 2013 [16]	Interstitial HDR IRT	TG-43 vs. Acuros BV (GBBS)	Patient cohort ($n = 49$)	Evaluation of dosimetric differences between TG-43 and GBBS accounting for tissue heterogeneities
Moura et al., 2015 [17]	HDR IRT QA	TG43 vs. Acuros BV (GBBS) vs. MC	Development of a heterogeneous phantom for TPS validation	Evaluation of heterogeneity effects on TG-43 dose calculation accuracy
Ballester et al., 2015 [18]	HDR IRT QA	Acuros BV vs. ACE vs. MC	Development of a reference HDR source and phantom dataset	MC benchmarking of MBDCAs
Zwierzchowski et al., 2016 [19]	Gynecological HDR IRT	ACE	Water phantom study with film dosimetry	Development of experimental verification methods for TPS dose calculations in HDR IRT
Ma et al., 2017 [20]	HDR IRT QA	Acuros BV vs. ACE vs. MC	Development of a shielded applicator test case for TG-186 commissioning	Validation of MBDCAs against MC simulations
Ababneh et al., 2018 [21]	HDR IRT QA	MC	Virtual phantom simulations	Development of physics components supporting MBDCAs dose calculations
Pappas et al., 2018 [22]	Contact HDR IRT	TG-43 vs. ACE vs. MC	Gel dosimeter phantom study with MC benchmarking	Experimental benchmarking of MBDCAs against TG-43 and MC
Sinnatamby et al., 2018 [23]	General HDR IRT	Acuros BV vs. gamma analysis	Tissue-equivalent phantom study with film dosimetry	Commissioning and verification of heterogeneity-aware MBDCAs algorithms

Table 1. Cont.

	Application	Dose Calculation Approach	Study Model	Primary Aim
Scherf et al., 2022 [24]	HDR IRT QA	ACE	Phantom study with ionization chamber measurements	Evaluation of imaging-related effects on HU-based dose calculations
Zwierzchowski et al., 2022 [25]	Contact HDR IRT	TG-43 vs. ACE	Phantom verification of dose distributions with lead shielding	Experimental validation of MBDCAs in heterogeneous conditions
Peppia et al., 2023 [26]	Interstitial breast HDR IRT	ACE, Acuros BV vs. MC	Development of computational test case for algorithm commissioning	Development of computational patient models for MBDCAs benchmarking
Fagerstrom et al., 2024 [27]	HDR IRT QA	Acuros BV	Standardized TG-186 test cases with CT/water-based datasets	Commissioning and validation of MBDCAs implementation in HDR IRT
Rossi et al., 2024 [28]	Contact HDR IRT	TG-43 vs. ACE vs. MC	Clinical treatment planning case with MC benchmarking	Evaluation of dose calculation accuracy: MBDCAs vs. TG-43 in superficial HDR IRT
Silvus et al., 2024 [29]	In vitro irradiation HDR IRT	TG-43 vs. Acuros BV vs. gamma analysis vs. film measurements	In vitro cell-culture irradiation with film dosimetry	Development and validation of a 3D-printed irradiation platform for HDR IRT studies
Meftahi et al., 2024 [30]	Gynecological HDR IRT	Acuros BV vs. MC	Virtual water phantom with applicator models	Evaluation of applicator material effects on HDR IRT dose calculations
Salamat et al., 2024 [31]	Contact HDR IRT	TG-43 vs. MC vs. film measurements	Phantom study	Evaluation of surface mould applicators and MBDCAs accuracy
Shajid et al., 2024 [32]	Gynecological HDR IRT	TG-43 vs. ACE	Patient cohort ($n = 30$)	Evaluation of dosimetric differences between TG-43 and TG-186 in intracavitary HDR IRT
Karius et al., 2024 [13]	HDR IRT QA	TG-43 vs. ACE	Patient cohort ($n = 26$) and phantom study	Evaluation of CBCT-based MBDCAs feasibility and dosimetric accuracy in adaptive HDR IRT
Moghadam et al., 2025 [33]	HDR IRT QA	MC	Development of graphical interface for MC IRT dose calculations	Development of computational tools for MC dose calculations in HDR IRT
Rosa et al., 2025 [34]	Contact HDR IRT	TG-43 vs. ACE	Evaluation of a 3D-printed multilayer applicator with high-density shielding	Evaluation of TG-186 impact on OAR dose and personalized HDR IRT
Peppia et al., 2026 [35]	Gynecological HDR IRT	ACE vs. MC	Development of clinical test cases for commissioning and QA	Development of computational test cases for commissioning HDR IRT algorithms

Table 2. Overview of the studies included in the literature review on dose calculation algorithms in HDR IRT for patient studies.

	Application	Dose Calculation Approach	Study Model	Primary Aim
Zourari et al., 2015 [36]	Interstitial HDR IRT breast	TG-43 vs. ACE	Patient cohort ($n = 38$)	Evaluation of DVH and plan-quality differences between TG-43 and MBDCAs
Terribilini et al., 2017 [37]	Interstitial HDR IRT breast	TG-43 vs. ACE vs. MC	Clinical evaluation of ACE in HDR breast IRT plans	Performance evaluation of MBDCAs in heterogeneous dose calculation scenarios
Abe et al., 2018 [38]	Gynecological HDR IRT	TG-43 vs. ACE vs. MC	Clinical evaluation of MBDCAs in IRT	Clinical evaluation of MBDCAs performance in heterogeneous anatomical conditions
Duque et al., 2020 [39]	Interstitial liver HDR IRT	TG-43 vs. MC	Evaluation of model-based calculations in CT-guided liver IRT	Evaluation of TG-186 vs. TG-43 in CT-guided interstitial HDR IRT
Scherf et al., 2021 [40]	Contact HDR IRT	TG-43 vs. ACE	Patient cohort ($n = 6$)	Evaluation of mould material heterogeneities and dose calculation corrections
Sinnatamby et al., 2021 [41]	Contact HDR IRT	TG-43 vs. Acuros BV (GBBS)	Patient cohort ($n = 25$)	Evaluation of dosimetric advantages of MBDCAs in chest-wall HDR IRT
Szlag et al., 2021 [42]	Contact HDR IRT	TG-43 vs. ACE	Patient cohort ($n = 11$)	Evaluation of tissue heterogeneity effects in superficial HDR IRT
Antaki et al., 2023 [43]	Prostate interstitial HDR IRT	MBDCA	Patient cohort ($n = 10$)	Development of optimization methods for IMBT treatment planning in HDR IRT
Placidi et al., 2023 [44]	Contact HDR IRT	TG-43 vs. ACE	Treatment planning study	Evaluation of bolus thickness and heterogeneity corrections on target coverage
Roussakis et al., 2024 [45]	Breast, head a neck, lung interstitial HDR IRT	TG-43 vs. Acuros BV (GBBS)	Patient cohort ($n = 59$)	Multi-site evaluation of dosimetric differences between TG-43 and MBDCAs
Radcliffe et al., 2025 [46]	Gynecological HDR IRT	TG-43 vs. Acuros BV	Patient cohort ($n = 32$)	Evaluation of dosimetric differences between TG-43 and MBDCAs in HDR IRT
Rosa et al., 2025 [47]	Contact HDR IRT	TG-43 vs. ACE	Patient cohort ($n = 10$) with simulations	Evaluation of geometric and material heterogeneities in contact HDR IRT
Licher et al., 2025 [48]	Contact HDR IRT	TG-43 vs. ACE	Evaluation of patient-specific 3D-printed mould applicators	Clinical evaluation of patient-specific mould HDR IRT
Schaller et al., 2025 [49]	Interstitial HDR IRT	TG-43 vs. ACE	Patient cohort ($n = 158$)	Evaluate dosimetric differences and correlate dose metrics with clinical outcomes and toxicity

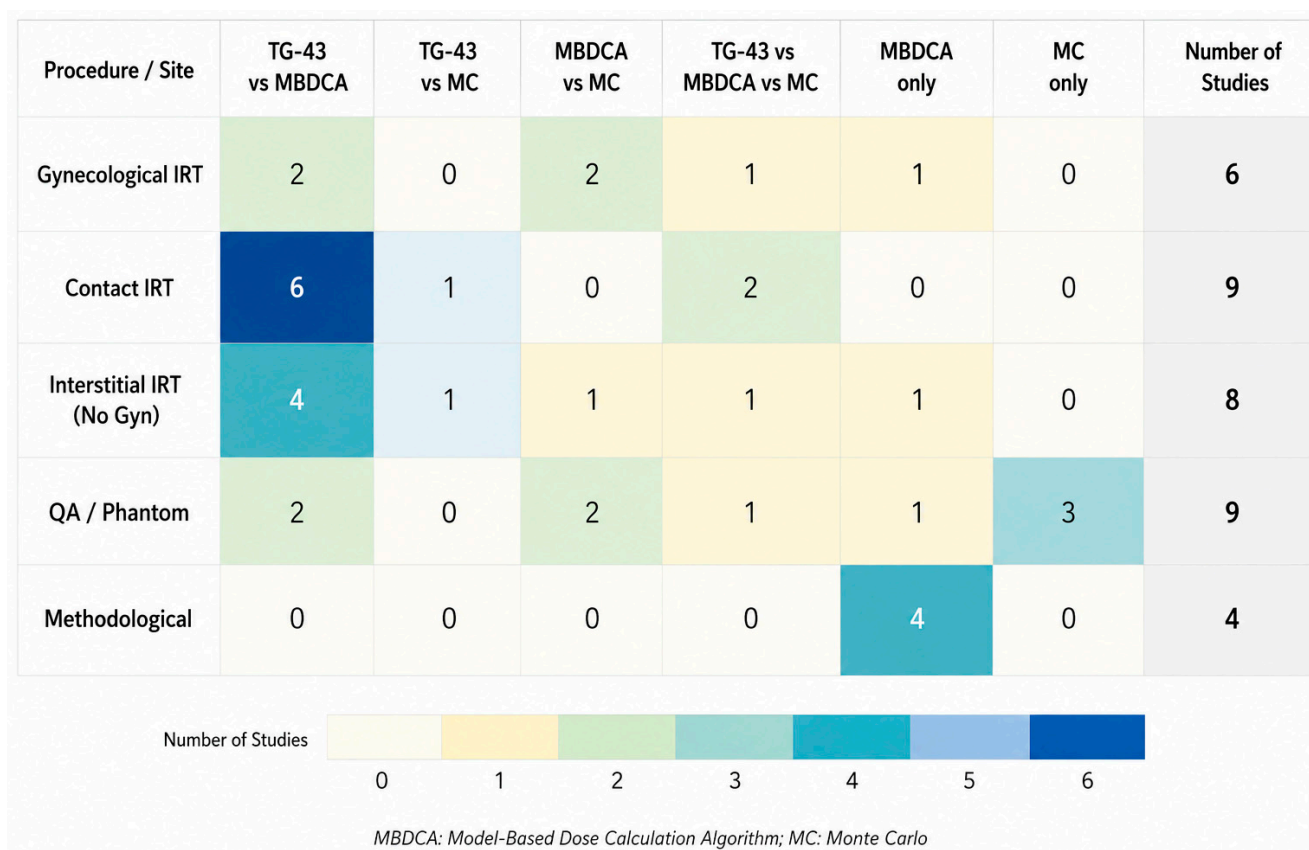


Figure 2. Distribution of the included studies according to clinical application and type of dose calculation comparison.

The dose calculation approaches investigated in the included studies were heterogeneous but predominantly involved comparisons between the conventional TG-43 water-based formalism and MBDCAs implemented according to the TG-186 recommendations, including deterministic solvers such as the ACE and the GBBS Acuros BV [2,4]. MC simulations were also frequently used, either as a reference standard for benchmarking deterministic algorithms or as an independent dose calculation framework [14]. The distribution of calculation approaches used in the reviewed studies is summarized in Figure 2, which illustrates the number of investigations performing comparisons between TG-43, MBDCA, and MC methods across the different clinical contexts.

Across the dataset, the most common comparison involved TG-43 versus MBDCAs, followed by comparisons between MBDCAs and MC simulations or studies including all three calculation approaches. A smaller number of publications focused exclusively on the development or implementation of MBDCAs or MC-based computational frameworks without performing direct comparisons between calculation methods. As shown in Figure 2, comparisons between TG-43 and MBDCAs represented the largest proportion of studies, particularly in contact and gynecological HDR IRT.

Several retrospective patient studies investigated the clinical impact of different dose calculation approaches. In interstitial HDR IRT cohorts including breast, head-and-neck, and lung implants, TG-43-based calculations predicted higher target coverage parameters compared with Acuros BV calculations, with reported differences in D90, V95, and V100 of approximately 2–5% [36,45]. However, not all studies have reported clinically relevant differences, with some investigations showing only minor dosimetric variations between TG-43 and model-based approaches, including studies with patient datasets primarily designed for methodological validation [13]. Comparable differences were observed in gynecological IRT investigations, where TG-43 calculations predicted higher target cover-

age and organ-at-risk dose values compared with ACE-based calculations [32,34,46]. In scenarios characterized by anatomical heterogeneities, such as the presence of air cavities in the rectum during cervical HDR IRT, differences between deterministic algorithms and MC simulations were reported to reach approximately 8–12% for rectal D2cm³ values [30,35]. In contrast, larger deviations have been reported in specific anatomical sites such as head and neck IRT, particularly in high-dose regions, where differences between TG-43 and MBDCAs calculations may reach up to approximately 15–20% [49].

Additional clinical evidence was reported for other anatomical sites. In CT-guided interstitial liver IRT, recalculation of treatment plans using TG-186-based algorithms resulted in lower dose estimates compared with TG-43 calculations. Differences in liver dose–volume parameters reached approximately –6% of the total liver volume, while reductions of up to –3.5% of the prescribed dose were reported for target coverage metrics [39].

Similar observations were reported in breast HDR treatments delivered using catheter flap moulds or accelerated partial breast irradiation techniques, where recalculation with Acuros BV resulted in lower dose parameters for both target volumes and surrounding organs at risk when compared with TG-43 calculations [41].

Superficial HDR IRT represented one of the most extensively investigated treatment scenarios. Comparisons between TG-43, MBDCAs, and MC simulations demonstrated pronounced differences in predicted dose distributions when full scatter conditions were not present. In large surface mould treatments for scalp lesions, TG-43 calculations were reported to overestimate dose values by approximately 10–20% at increasing distances from the implant [28]. Additional planning studies evaluating individualized mould treatments for facial or perinasal skin tumors reported lower target dose parameters when treatment plans were recalculated using TG-186-based algorithms [40]. Similar findings were observed in multi-catheter mould-based treatments and planning investigations for skin cancer IRT, where ACE-based recalculations resulted in reduced dose estimates for both target volumes and organs at risk compared with TG-43 calculations [42,44,47].

Several studies specifically investigated the impact of material and geometric heterogeneities on dose calculation accuracy. MC simulations evaluating high-density vaginal cylinder applicators demonstrated dose reductions of approximately 6–7% at the applicator surface compared with homogeneous water calculations [30]. Additional simulations showed that geometric factors such as air gaps between applicators and patient surfaces may significantly influence delivered dose, with reported reductions reaching approximately 15% in certain configurations [47].

Experimental validation studies were also widely represented in the literature. Phantom investigations using film dosimetry, gel dosimeters, and ionization chamber measurements were performed to verify the accuracy of treatment planning system calculations under heterogeneous conditions [17,22,23,25]. In these studies, heterogeneous phantom models composed of materials simulating different tissue densities were used to reproduce realistic clinical conditions. Experimental measurements combined with MC simulations demonstrated dose variations exceeding 10% when heterogeneous materials were introduced.

Additional methodological studies contributed to the development of benchmarking datasets and commissioning tools for MBDCAs. Several investigations described the generation of standardized HDR 192Ir source models, virtual water phantoms, and anthropomorphic computational phantoms derived from clinical IRT cases [18,20,26,35]. These datasets were used to benchmark deterministic algorithms against MC reference calculations. In these validation studies, deterministic algorithms such as Acuros BV and ACE reproduced MC dose distributions within approximately 1–2% in clinically relevant regions. For the purpose of this review, studies were categorized as QA/dosimetric studies when they focused on phantom validation, treatment planning comparisons, algorithm

verification, or quality assurance procedures, whereas patient studies included investigations based on clinical patient datasets and treatment planning analyses. The temporal distribution of the included studies is shown in Figure 3, with a higher prevalence of QA and dosimetric investigations compared with patient-based studies.

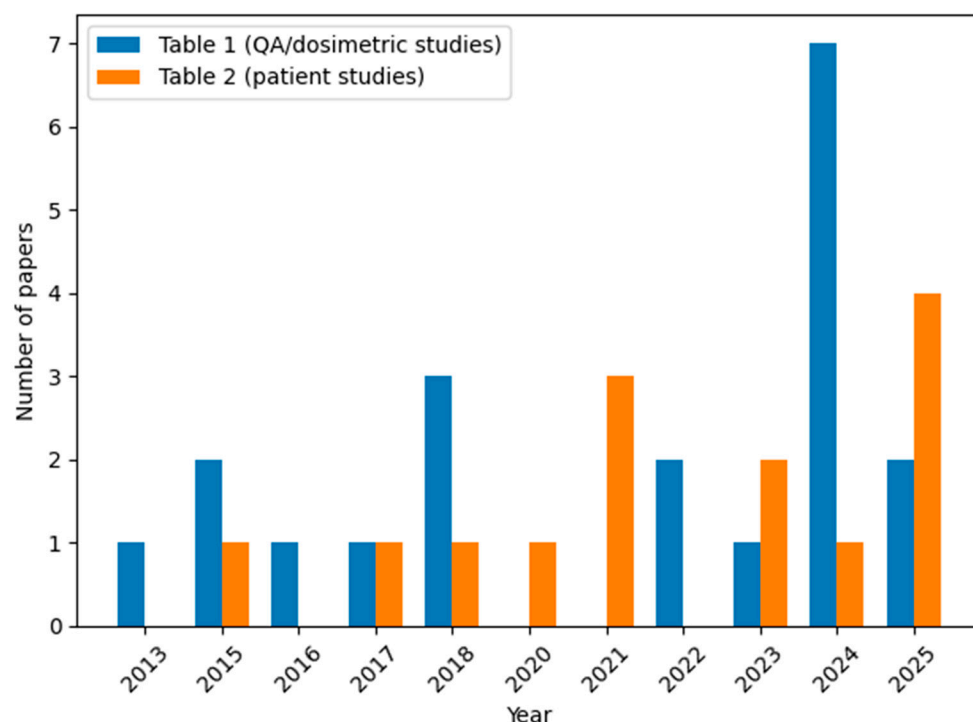


Figure 3. Temporal distribution of the included studies according to publication year, stratified by study type.

4. Discussion

The analyzed studies highlight the increasing interest in the adoption of advanced dose calculation approaches in modern HDR IRT. While the TG-43 formalism has historically represented the standard method for IRT dose calculation, its simplifying assumptions, particularly the use of a homogeneous water medium and the neglect of scatter conditions and material heterogeneities, limit its ability to accurately describe dose distributions in several clinically relevant situations [1–3]. At the same time, it should be acknowledged that the current clinical experience regarding dose–outcome relationships is largely based on TG-43 calculations, and this legacy must be carefully considered when interpreting results obtained with more advanced algorithms. The results of the present review confirm that differences between TG-43 and model-based calculations are consistently observed across multiple anatomical sites and treatment techniques. However, clinical evidence supporting MBDCAs is still evolving, and further experience is required before their routine and standardized clinical implementation can be fully established. In this context, and in agreement with the joint GEC-ESTRO and AAPM working group recommendations, it is advisable to report TG-43 and TG-186-based dose calculations simultaneously whenever feasible, to facilitate comparison and support clinical transition.

Although deterministic algorithms such as ACE and Acuros BV provide calculation times that are generally compatible with routine clinical workflows, dual reporting inevitably increases treatment planning complexity by requiring additional plan verification, comparison of dose metrics, and interpretation of differences between TG-43 and TG-186 results. Furthermore, successful implementation requires comprehensive commissioning procedures, including CT-to-material calibration, validation of material assignment, and

algorithm-specific quality assurance, together with appropriate staff training to ensure consistent clinical interpretation of the reported dose metrics.

This transitional approach is particularly important because the majority of currently accepted prescription protocols, dose constraints for organs at risk, and dose–response relationships have been established using TG-43-based calculations. Consequently, although MBDCAs provide a more physically realistic representation of dose deposition, direct substitution of historical TG-43 dose metrics with TG-186-derived values should be approached with caution until sufficient clinical outcome data become available.

One of the most common observations emerging from the analyzed studies is the tendency of TG-43-based calculations to predict higher dose values compared with model-based approaches. Although these differences are generally modest in relatively homogeneous conditions, they become more pronounced in the presence of heterogeneities or complex geometries. This aspect is particularly relevant in treatment scenarios characterized by interfaces between materials with markedly different physical densities, where simplified water-based assumptions cannot adequately represent the underlying radiation interaction conditions.

Importantly, the dosimetric differences reported between TG-43 and MBDCAs should not be interpreted uniformly across all HDR IRT applications, as their magnitude depends on the clinical scenario and may range from only a few percent in relatively homogeneous conditions to clinically relevant deviations in highly heterogeneous treatment geometries. From a practical perspective, the available evidence suggests that TG-43 remains an appropriate and clinically acceptable dose calculation approach for conventional HDR IRT treatments performed under relatively homogeneous conditions, using standard applicators and full scatter geometries, where dosimetric differences are generally limited. Conversely, the use of MBDCAs should be strongly considered whenever significant tissue or material heterogeneities, air gaps, shielding components, patient-specific 3D-printed applicators, or limited-scatter conditions are present, as these situations are associated with the largest discrepancies from TG-43-based calculations.

Contact HDR IRT represents a clear example of such conditions. Superficial treatments often involve complex geometries, limited scatter conditions, and interfaces between tissue, air, and applicator materials. Several studies included in this review reported that TG-43 calculations may overestimate the delivered dose in superficial mould-based treatments, especially in large treatment areas or when backscatter conditions are reduced. In these contexts, MBDCAs provide a more realistic representation of photon transport, enabling improved characterization of dose gradients near the treatment surface and at material interfaces [50,51].

Another important aspect highlighted by the analyzed studies concerns the influence of applicator materials on dose calculations. Many modern HDR IRT procedures employ applicators composed of materials with physical properties significantly different from water. This is particularly relevant for gynecological applicators, multilayer moulds, or shielding components, which may introduce local attenuation and scattering effects not accounted for by the TG-43 formalism. The reviewed studies demonstrate that such heterogeneities can produce measurable variations in dose distributions, particularly near applicator surfaces and in regions where high-density materials are present.

These considerations have become even more relevant with the increasing adoption of additive manufacturing technologies in IRT. Three-dimensional printing enables the fabrication of customized applicators and moulds tailored to patient-specific anatomy, supporting the development of more personalized HDR IRT. However, the materials used in additive manufacturing may exhibit a wide range of densities and compositions, creating heterogeneous radiation transport environments that cannot be fully represented by homo-

geneous water-based assumptions. Accurate modeling of these heterogeneities therefore becomes important for reliable dose estimation in increasingly personalized treatment geometries. Although the proportion of studies currently reporting the use of 3D-printed applicators remains relatively limited (approximately 9% in the analyzed literature), the adoption of additive manufacturing in radiation oncology is rapidly expanding. As a consequence, questions that in the past could be considered mainly methodological or academic, such as the impact of material composition and density on dose calculation, are becoming progressively more relevant for routine clinical practice. With the expected growth of patient-specific devices and customized applicator designs, the accurate modeling of these heterogeneous materials is likely to represent an increasingly important aspect of treatment planning in HDR IRT.

Moreover, precise dosimetric characterization is also essential in translational research settings, where HDR IRT is used in experimental irradiation platforms for radiobiological studies. In these contexts, heterogeneity-aware approaches such as MBDCAs or Monte Carlo simulations can improve dose accuracy and support the translation of experimental findings into clinically relevant HDR IRT applications [6,10].

To improve reproducibility across preclinical studies, quality assurance of these experimental platforms should include CT-based geometric characterization of the irradiation setup, validation of the physical properties of all irradiation materials, independent dosimetric verification using radiochromic films or equivalent detectors, and benchmarking of deterministic algorithms against Monte Carlo simulations whenever feasible. The adoption of standardized commissioning procedures for small-volume irradiation systems would further enhance the comparability and translational value of radiobiological investigations performed with HDR IRT.

The reliability of MBDCAs is further supported by their agreement with MC simulations, which are widely considered the reference standard for radiation transport modeling. Several benchmarking studies reported in the literature demonstrate that deterministic algorithms such as GBBS and ACE can reproduce MC dose distributions within a few percent in clinically relevant regions [18,20,26,27]. This level of agreement provides confidence in the use of model-based approaches for treatment planning, particularly in clinical scenarios where heterogeneity effects are expected to play a significant role.

Experimental validation studies also contribute important evidence supporting the adoption of model-based dose calculations. Phantom measurements using film dosimetry, gel detectors, or ionization chambers consistently demonstrate improved agreement between calculated and measured dose distributions when heterogeneity-aware algorithms are employed [17,22,23]. In heterogeneous phantom configurations, dose deviations exceeding 10% have been reported when simplified water-based calculations are used, highlighting the importance of accurate modeling of material composition and density in treatment planning systems.

Another relevant consideration concerns the role of imaging-based material assignment in TG-186 implementations. Since MBDCAs rely on CT-derived density information to describe patient anatomy and applicator materials, uncertainties in Hounsfield unit conversion or incorrect material assignment may influence calculated dose distributions. In this context, it is also important to distinguish between implementations such as ACE that directly use voxel-wise CT Hounsfield numbers and those in which uniform materials can be assigned to contoured structures, allowing the user to override image-based heterogeneities with predefined densities. The presence of high-density components or contrast agents, which may be intentionally administered during treatment planning to improve tumor visualization, may further complicate this process. Consequently, appropriate cali-

bration procedures and careful commissioning remain essential steps when implementing MBDCAs in clinical practice.

This aspect becomes particularly relevant when patient-specific 3D-printed applicators are employed. Commercial additive manufacturing materials, including different grades of PLA, PETG, TPU, and photopolymer resins, may exhibit considerable variability in physical density and CT Hounsfield Unit values depending not only on the material itself but also on manufacturer specifications, printing parameters (e.g., infill percentage), and imaging protocols. Consequently, uncertainties in CT-to-material conversion or inaccurate material assignment may propagate into dose calculations performed with model-based dose calculation algorithms (MBDCAs), such as Acuros BV and ACE. These considerations underline the importance of dedicated material characterization, commissioning, and validation procedures before the routine clinical implementation of patient-specific 3D-printed devices.

From a practical perspective, although TG-186-based MBDCAs improve dosimetric accuracy by accounting for tissue heterogeneities, their widespread clinical implementation still presents several challenges beyond their physical accuracy. Compared with conventional TG-43 workflows, MBDCAs require more extensive commissioning procedures, including validation of CT-to-material conversion, verification of material assignment, and algorithm-specific quality assurance. Their implementation also requires dedicated training of medical physicists and radiation oncologists to ensure the appropriate interpretation of dose metrics and a thorough understanding of algorithm-specific assumptions. Furthermore, integration into routine clinical workflows may increase planning complexity and workload, particularly during the transition phase in which both TG-43- and TG-186-based calculations may need to be evaluated. Therefore, careful uncertainty management, together with compliance with current professional recommendations and local regulatory requirements, remains essential for the safe and effective clinical implementation of model-based dose calculation algorithms.

Beyond their immediate clinical implications, MBDCAs also enable the development of new research directions in IRT. Advanced treatment techniques, including intensity-modulated IRT and sophisticated optimization strategies based on complex dwell time and dwell position configurations, require accurate dose calculation methods capable of modeling heterogeneous radiation transport conditions. In addition, the growing use of customized applicators, shielding components, and moulds produced through additive manufacturing technologies further increases the complexity of the radiation transport environment [34].

In this evolving technological context, the progressive transition from dose calculation approaches based on homogeneous water assumptions toward algorithms capable of explicitly accounting for tissue and material heterogeneities may therefore be considered increasingly desirable. Such developments reflect the continuous advancement of both procedural techniques and supporting technologies in HDR IRT, including the use of customized applicators, shielding structures, and patient-specific moulds. Within this framework, heterogeneity-aware computational models provide a more flexible and physically realistic representation of modern treatment geometries.

A limitation of this review is that the included studies are heterogeneous in terms of clinical applications, study designs, and validation methods, which limits direct quantitative comparison between results. Overall, the available evidence indicates that the integration of MBDCAs represents an important step toward improving the physical accuracy of IRT treatment planning. At the same time, the transition from conventional TG-43 workflows to heterogeneity-aware dose calculations requires appropriate commissioning procedures, validation studies, and clinical experience to ensure reliable implementation.

Future investigations should continue to explore the impact of advanced dose calculation methods across different anatomical sites, applicator designs, and emerging technologies in HDR IRT.

This review has several limitations. First, as a narrative review, it was designed to provide a qualitative overview of the current evidence rather than a systematic synthesis, and therefore no formal systematic review methodology was applied. Second, the literature search was restricted to the PubMed and Scopus databases; consequently, relevant studies indexed in other databases or available in the grey literature may not have been identified. Finally, as with any review based on published literature, the findings may be influenced by publication bias, since studies reporting positive or significant findings are more likely to be published. These limitations should be considered when interpreting the conclusions of the present review.

5. Conclusions

The evidence reviewed suggests that the water-based TG-43 formalism remains a robust and widely used approach for dose calculation in HDR IRT. However, the increasing adoption of advanced procedures, customized applicators, shielding components, and 3D-printed devices introduces heterogeneous conditions that may not be fully represented by homogeneous water assumptions. In the era of emerging technologies in HDR IRT, the integration of MBDCAs capable of accounting for tissue and material heterogeneities appears increasingly relevant for accurate dose estimation.

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Abbreviations

The following abbreviations are used in this manuscript:

3D	Three-Dimensional
AAPM	American Association of Physicists in Medicine
ACE	Advanced Collapsed Cone Engine
CBCT	Cone-Beam Computed Tomography
CT	Computed Tomography
GBBS	Grid-Based Boltzmann Solver
GEC-ESTRO	Groupe Européen de Curiethérapie—European Society for Radiotherapy and Oncology
HDR	High-Dose-Rate
HU	Hounsfield Unit
IMBT	Intensity-Modulated Brachytherapy
IRT	Interventional Radiotherapy
LDR	Low-Dose-Rate
MC	Monte Carlo

MBDCA	Model-Based Dose Calculation Algorithm
MBDCAs	Model-Based Dose Calculation Algorithms
OAR	Organ At Risk
QA	Quality Assurance
TG-43	AAPM Task Group 43
TG-186	AAPM Task Group 186
TPS	Treatment Planning System

References

- Nath, R.; Anderson, L.L.; Luxton, G.; Weaver, K.A.; Williamson, J.F.; Meigooni, A.S. Dosimetry of interstitial brachytherapy sources: Recommendations of the AAPM Radiation Therapy Committee Task Group No. 43. *Med. Phys.* **1995**, *22*, 209–234. [\[CrossRef\]](#) [\[PubMed\]](#)
- Beaulieu, L.; Carlsson Tedgren, Å.; Carrier, J.; Davis, S.D.; Mourtada, F.; Rivard, M.J.; Thomson, R.M.; Verhaegen, F.; Wareing, T.A.; Williamson, J.F. Report of the Task Group 186 on model-based dose calculation methods in brachytherapy beyond the TG-43 formalism: Current status and recommendations for clinical implementation. *Med. Phys.* **2012**, *39*, 6208–6236. [\[CrossRef\]](#) [\[PubMed\]](#)
- Beaulieu, L.; Ballester, F.; Granero, D.; Tedgren, Å.C.; Haworth, A.; Lowenstein, J.R.; Ma, Y.; Mourtada, F.; Papagiannis, P.; Rivard, M.J.; et al. AAPM WGDCAB Report 372: A joint AAPM, ESTRO, ABG, and ABS report on commissioning of model-based dose calculation algorithms in brachytherapy. *Med. Phys.* **2023**, *50*, e946–e960. [\[CrossRef\]](#) [\[PubMed\]](#)
- Rivard, M.J.; Coursey, B.M.; DeWerd, L.A.; Hanson, W.F.; Saiful Huq, M.; Ibbott, G.S.; Mitch, M.G.; Nath, R.; Williamson, J.F. Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations. *Med. Phys.* **2004**, *31*, 633–674. [\[CrossRef\]](#) [\[PubMed\]](#)
- Tran, D.; Duong, T.; Wadi-Ramahi, S.; Bradley, D.; Chow, J.C.L. Beyond TG-43: A PRISMA-based systematic review on model-based dose-calculation algorithms in brachytherapy. *J. Appl. Clin. Med. Phys.* **2026**, *27*, e70627. [\[CrossRef\]](#) [\[PubMed\]](#)
- Papagiannis, P.; Pantelis, E.; Karaikos, P. Current state of the art brachytherapy treatment planning dosimetry algorithms. *Br. J. Radiol.* **2014**, *87*, 20140163. [\[CrossRef\]](#) [\[PubMed\]](#)
- Rosa, E.; Raponi, S.; Fionda, B.; Vaccaro, M.; Lancellotta, V.; Napolitano, A.; Ciasca, G.; Bannoni, L.; Cornacchione, P.; Tagliaferri, L.; et al. 3D-Printed Devices in Interventional Radiotherapy (Brachytherapy) Applications: A Literature Review. *J. Pers. Med.* **2025**, *15*, 262. [\[CrossRef\]](#) [\[PubMed\]](#)
- Pinckney, R.; Parupelli, S.K.; Sandwall, P.; Chang, S.; Desai, S. A Review of 3D-Printed Medical Devices for Cancer Radiation Therapy. *Bioengineering* **2026**, *13*, 115. [\[CrossRef\]](#) [\[PubMed\]](#)
- Kirisits, C.; Rivard, M.J.; Baltas, D.; Ballester, F.; De Brabandere, M.; Van Der Laarse, R.; Niatsetski, Y.; Papagiannis, P.; Hellebust, T.P.; Perez-Calatayud, J.; et al. Review of clinical brachytherapy uncertainties: Analysis guidelines of GEC-ESTRO and the AAPM. *Radiother. Oncol.* **2014**, *110*, 199–212. [\[CrossRef\]](#) [\[PubMed\]](#)
- Rosa, E.; Raponi, S.; Fionda, B.; Napolitano, A.; Lancellotta, V.; Vaccaro, M.; Angeli, M.D.; Pastore, F.; Bannoni, L.; Dragonetti, P.; et al. Impact of applicator curvature in contact interventional radiotherapy (brachytherapy) for skin cancer: Exploring the “Nautilus Effect”. *Phys. Med.* **2026**, *145*, 105767. [\[CrossRef\]](#) [\[PubMed\]](#)
- Rosa, E.; Niccolini, B.; Di Santo, R.; Fionda, B.; Vaccaro, M.; Placidi, E.; Tabolacci, E.; De Spirito, M.; Mangoni, M.; Tagliaferri, L.; et al. A gap analysis integrating In vitro—Research in HDR interventional radiotherapy (Modern Brachytherapy): Challenges, limitations, and future directions. *Appl. Radiat. Isot.* **2026**, *227*, 112284. [\[CrossRef\]](#) [\[PubMed\]](#)
- Rivard, M.J.; Venselaar, J.L.M.; Beaulieu, L. The evolution of brachytherapy treatment planning. *Med. Phys.* **2009**, *36*, 2136–2153. [\[CrossRef\]](#) [\[PubMed\]](#)
- Karius, A.; Shariff, M.; Schaller, S.; Lotter, M.; Strnad, V.; Lackner, N.; Fietkau, R.; Bert, C.; Merten, R.; Schweizer, C. Is model-based dose calculation based on cone-beam computed tomography suitable for adaptive treatment planning in brachytherapy? *Strahlenther. Onkol.* **2025**, *201*, 57–70. [\[CrossRef\]](#) [\[PubMed\]](#)
- Enger, S.A.; Vijande, J.; Rivard, M.J. Model-Based Dose Calculation Algorithms for Brachytherapy Dosimetry. *Semin. Radiat. Oncol.* **2020**, *30*, 77–86. [\[CrossRef\]](#) [\[PubMed\]](#)
- Yousif, Y.A.M.; Osman, A.F.I.; Halato, M.A. A review of dosimetric impact of implementation of model-based dose calculation algorithms (MBDCAs) for HDR brachytherapy. *Phys. Eng. Sci. Med.* **2021**, *44*, 871–886. [\[CrossRef\]](#) [\[PubMed\]](#)
- Siebert, F.-A.; Wolf, S.; Kóvacs, G. Head and neck 192 Ir HDR-brachytherapy dosimetry using a grid-based Boltzmann solver. *J. Contemp. Brachytherapy* **2013**, *4*, 232–235. [\[CrossRef\]](#) [\[PubMed\]](#)
- Moura, E.S.; Micka, J.A.; Hammer, C.G.; Culbertson, W.S.; DeWerd, L.A.; Rostelato, M.E.C.M.; Zeituni, C.A. Development of a phantom to validate high-dose-rate brachytherapy treatment planning systems with heterogeneous algorithms. *Med. Phys.* **2015**, *42*, 1566–1574. [\[CrossRef\]](#) [\[PubMed\]](#)

18. Ballester, F.; Carlsson Tedgren, Å.; Granero, D.; Haworth, A.; Mourtada, F.; Fonseca, G.P.; Zourari, K.; Papagiannis, P.; Rivard, M.J.; Siebert, F.-A.; et al. A generic high-dose rate¹⁹² Ir brachytherapy source for evaluation of model-based dose calculations beyond the TG-43 formalism: Model-based dose calculations beyond the TG-43 formalism. *Med. Phys.* **2015**, *42*, 3048–3062. [[CrossRef](#)] [[PubMed](#)]
19. Zwierzchowski, G.; Bieleńda, G.; Skowronek, J.; Mazur, M. Film based verification of calculation algorithms used for brachytherapy planning-getting ready for upcoming challenges of MBDCa. *J. Contemp. Brachytherapy* **2016**, *4*, 326–335. [[CrossRef](#)] [[PubMed](#)]
20. Ma, Y.; Vijande, J.; Ballester, F.; Tedgren, Å.C.; Granero, D.; Haworth, A.; Mourtada, F.; Fonseca, G.P.; Zourari, K.; Papagiannis, P.; et al. A generic TG-186 shielded applicator for commissioning model-based dose calculation algorithms for high-dose-rate¹⁹² Ir brachytherapy. *Med. Phys.* **2017**, *44*, 5961–5976. [[CrossRef](#)] [[PubMed](#)]
21. Ababneh, E.; Dababneh, S.; Wadi-Ramahi, S.; Sharaf, J. Physics elements of an algorithm for brachytherapy dose calculation in homogeneous media for 192 Ir source. *Radiat. Phys. Chem.* **2018**, *149*, 90–103. [[CrossRef](#)]
22. Pappas, E.P.; Peppas, V.; Hourdakis, C.J.; Karaikos, P.; Papagiannis, P. On the use of a novel Ferrous Xylenol-orange gelatin dosimeter for HDR brachytherapy commissioning and quality assurance testing. *Phys. Med.* **2018**, *45*, 162–169. [[CrossRef](#)] [[PubMed](#)]
23. Sinnatamby, M.; Nagarajan, V.; Kanipakam, R.S.; Karunanidhi, G.; Neelakandan, V.; Kandasamy, S. Verification of Radiation Fluence using Stack Film in HDR Brachytherapy with Heterogeneity Algorithm. *J. Clin. Diagn. Res.* **2018**, *12*, XC05–XC10. [[CrossRef](#)]
24. Scherf, C.; Ramm, U.; Stein, T.; Trommel, M.; Tselis, N.; Chatzikonstantinou, G.; Diefenhardt, M.; Rödel, C.; Köhn, J.; Licher, J. Effects of iodinated contrast agent on HU-based dose calculation and dose delivered in iridium-192 high-dose-rate brachytherapy. *J. Contemp. Brachytherapy* **2022**, *14*, 80–86. [[CrossRef](#)] [[PubMed](#)]
25. Zwierzchowski, G.; Bieleńda, G.; Szymbor, A.; Boehlke, M. Personalized Superficial HDR Brachytherapy—Dosimetric Verification of Dose Distribution with Lead Shielding of Critical Organs in the Head and Neck Region. *J. Pers. Med.* **2022**, *12*, 1432. [[CrossRef](#)] [[PubMed](#)]
26. Peppas, V.; Thomson, R.M.; Enger, S.A.; Fonseca, G.P.; Lee, C.; Lucero, J.N.E.; Mourtada, F.; Siebert, F.; Vijande, J.; Papagiannis, P. A MC-based anthropomorphic test case for commissioning model-based dose calculation in interstitial breast 192-Ir HDR brachytherapy. *Med. Phys.* **2023**, *50*, 4675–4687. [[CrossRef](#)] [[PubMed](#)]
27. Fagerstrom, J.M. Practical experience with initial quality assurance of a high dose rate brachytherapy grid-based Boltzmann solver algorithm. *J. Appl. Clin. Med. Phys.* **2024**, *25*, e14392. [[CrossRef](#)] [[PubMed](#)]
28. Rossi, G.; Peppas, V.; Gaaney, M.; Kollefrath, M.; Sprave, T.; Papagiannis, P.; Baltas, D. On the impact of improved dose calculation accuracy in clinical treatment planning for superficial high-dose-rate brachytherapy of extensive scalp lesions. *Phys. Imaging Radiat. Oncol.* **2024**, *32*, 100673. [[CrossRef](#)] [[PubMed](#)]
29. Silvas, A.; Mazur, T.R.; Goddu, S.M.; Memming, E.; Zoberi, J.E.; Markovina, S.; Altman, M.B. Dosimetric evaluation of a novel modular cell irradiation platform for multi-modality in vitro studies including high dose rate brachytherapy. *Brachytherapy* **2024**, *23*, 549–558. [[CrossRef](#)] [[PubMed](#)]
30. Meftahi, M.; Song, W.Y. The effect of vaginal cylinder inhomogeneity on the HDR brachytherapy dose calculations using Monte Carlo simulations. *J. Appl. Clin. Med. Phys.* **2024**, *25*, e14228. [[CrossRef](#)] [[PubMed](#)]
31. Salamat, F.; Siavashpour, Z.; Sadeghi, M.; Jaber, R.; Gholami, S. Dosimetric evaluation and Monte Carlo simulation of a new proposed surface brachytherapy mould. *J. Contemp. Brachytherapy* **2024**, *16*, 279–288. [[CrossRef](#)] [[PubMed](#)]
32. Shajid, S.M.; Aggarwal, L.M.; Mourya, A.; Choudhary, S.; Prian, G.; Singh, A.; Oommen, S. A comparison of TG-43 and TG-186 dose calculation algorithms for treatment planning of intra-cavitary brachytherapy using tandem and ovoid applicator. *J. Contemp. Brachytherapy* **2024**, *16*, 289–296. [[CrossRef](#)] [[PubMed](#)]
33. Moghadam, N.; Akbari, F.; Jarvis, S.; Martinov, M.; Thibodeau, M.; Zhang, C.; Cygler, J.E.; Thomson, R.M. A graphical user interface for Monte Carlo dose calculations for brachytherapy with egs_brachy. *Med. Phys.* **2025**, *52*, 5017–5025. [[CrossRef](#)] [[PubMed](#)]
34. Rosa, E.; Raponi, S.; Fionda, B.; Vaccaro, M.; Napolitano, A.; Lancellotta, V.; Pastore, F.; Ciasca, G.; Siebert, F.-A.; Tagliaferri, L.; et al. Intensity-Modulated Interventional Radiotherapy (Modern Brachytherapy) Using 3D-Printed Applicators with Multilayer Geometry and High-Density Shielding Materials for the NMSC Treatment. *J. Pers. Med.* **2025**, *15*, 460. [[CrossRef](#)] [[PubMed](#)]
35. Peppas, V.; Robitaille, M.; Akbari, F.; Enger, S.A.; Thomson, R.M.; Mourtada, F.; Fonseca, G.P. Clinical test cases for commissioning, QA, and benchmarking of model-based dose calculation algorithms in¹⁹² Ir HDR gynecologic tandem and ring brachytherapy. *Med. Phys.* **2026**, *53*, e70260. [[CrossRef](#)] [[PubMed](#)]
36. Zourari, K.; Major, T.; Herein, A.; Peppas, V.; Polgár, C.; Papagiannis, P. A retrospective dosimetric comparison of TG43 and a commercially available MBDCa for an APBI brachytherapy patient cohort. *Phys. Med.* **2015**, *31*, 669–676. [[CrossRef](#)] [[PubMed](#)]
37. Terribilini, D.; Vitzthum, V.; Volken, W.; Frei, D.; Loessl, K.; Van Veelen, B.; Manser, P.; Fix, M.K. Performance evaluation of a collapsed cone dose calculation algorithm for HDR Ir-192 of APBI treatments. *Med. Phys.* **2017**, *44*, 5475–5485. [[CrossRef](#)] [[PubMed](#)]

38. Abe, K.; Kadoya, N.; Sato, S.; Hashimoto, S.; Nakajima, Y.; Miyasaka, Y.; Ito, K.; Umezawa, R.; Yamamoto, T.; Takahashi, N.; et al. Impact of a commercially available model-based dose calculation algorithm on treatment planning of high-dose-rate brachytherapy in patients with cervical cancer. *J. Radiat. Res.* **2018**, *59*, 198–206. [[CrossRef](#)] [[PubMed](#)]
39. Duque, A.S.; Corradini, S.; Kamp, F.; Seidensticker, M.; Streitharth, F.; Kurz, C.; Walter, F.; Parodi, K.; Verhaegen, F.; Ricke, J.; et al. The dosimetric impact of replacing the TG-43 algorithm by model based dose calculation for liver brachytherapy. *Radiat. Oncol.* **2020**, *15*, 60. [[CrossRef](#)] [[PubMed](#)]
40. Scherf, C.; Licher, J.; Mletzko, C.; Trommel, M.; Tselis, N.; Chatzikonstantinou, G.; Diefenhardt, M.; Rödel, C.; Köhn, J.; Ramm, U. Individualized mould-based high-dose-rate brachytherapy for perinasal skin tumors: Technique evaluation from a dosimetric point of view. *J. Contemp. Brachytherapy* **2021**, *13*, 179–187. [[CrossRef](#)] [[PubMed](#)]
41. Sinnatamby, M.; Neelakandan, V.; Karunanidhi, G.; Kandasamy, S.; Ramapandian, S.; Kannan, M.; Sampath, E. Impact of GBBS algorithm on post-mastectomy scar boost irradiation of breast using catheter flap. *J. Contemp. Brachytherapy* **2021**, *13*, 310–317. [[CrossRef](#)] [[PubMed](#)]
42. Szlag, M.; Kellas-Ślęczka, S.; Wojcieszek, P.; Stankiewicz, M.; Cholewka, A.; Pruefer, A.; Krzysztofiak, T.; Lelek, P.; Stąpór-Fudzińska, M.; Ślosarek, K. Advanced dose calculation algorithm in superficial brachytherapy—The impact of tissue inhomogeneity on treatment plan dosimetry. *J. Contemp. Brachytherapy* **2021**, *13*, 441–446. [[CrossRef](#)] [[PubMed](#)]
43. Antaki, M.; Renaud, M.-A.; Morcos, M.; Seuntjens, J.; Enger, S.A. Applying the column generation method to the intensity modulated high dose rate brachytherapy inverse planning problem. *Phys. Med. Biol.* **2023**, *68*, 065007. [[CrossRef](#)] [[PubMed](#)]
44. Placidi, E.; Fionda, B.; Rosa, E.; Lancellotta, V.; Napolitano, A.; De Angeli, M.; Pastore, F.; Antonietta Gambacorta, M.; Indovina, L.; Tagliaferri, L.; et al. Dosimetric impact of applying a model-based dose calculation algorithm for skin cancer brachytherapy (interventional radiotherapy). *J. Contemp. Brachytherapy* **2023**, *15*, 448–452. [[CrossRef](#)] [[PubMed](#)]
45. Roussakis, Y.; Antorkas, G.; Georgiou, L.; Strouthos, I.; Karagiannis, E.; Zamboglou, C.; Ferentinos, K.; Zamboglou, N.; Anagnostopoulos, G. Dosimetric comparison of AcurosTM BV and AAPM TG-43 formalism for interstitial iridium-192 high-dose-rate brachytherapy. *J. Contemp. Brachytherapy* **2024**, *16*, 211–218. [[CrossRef](#)] [[PubMed](#)]
46. Radcliffe, B.A.; Kim, Y.; Raffi, J.; Ayala-Peacock, D.N.; Stephens, S.J.; Chino, J.; Meltsner, S.; Craciunescu, O. Retrospective assessment of HDR brachytherapy dose calculation methods in locally advanced cervical cancer patients: AcurosBV vs. AAPM TG43 formalism. *J. Appl. Clin. Med. Phys.* **2025**, *26*, e14549. [[CrossRef](#)] [[PubMed](#)]
47. Rosa, E.; Fionda, B.; Vaccaro, M.; Placidi, E.; Lancellotta, V.; Napolitano, A.; Pastore, F.; Greco, F.; Dragonetti, P.; La Milia, M.C.; et al. Dosimetric Impact of Air Gaps in High-Dose-Rate Contact Interventional Radiotherapy (Modern Brachytherapy) for Non-Melanoma Skin Cancer of the Ear. *J. Clin. Med.* **2025**, *14*, 7790. [[CrossRef](#)] [[PubMed](#)]
48. Licher, J.; Achenbach, J.; Köhn, J.; Diefenhardt, M.; Fleischmann, M.; Rödel, C.; Tselis, N.; Ramm, U.; Scherf, C. Advantages of 3D printed patient-individual moulds in brachytherapy for facial skin cancer. *Strahlenther. Onkol.* **2025**, *201*, 940–952. [[CrossRef](#)] [[PubMed](#)]
49. Schaller, S.; Strnad, V.; Schweizer, C.; Lubgan, D.; Merten, R.; Fietkau, R.; Bert, C.; Karius, A. Comparison of dose calculation approaches and clinical dose–response in image-guided head&neck brachytherapy of the oral cavity. *Clin. Transl. Radiat. Oncol.* **2025**, *53*, 100968. [[CrossRef](#)] [[PubMed](#)]
50. Fionda, B.; Placidi, E.; Rosa, E.; Lancellotta, V.; Stimato, G.; De Angeli, M.; Ciardo, F.G.; Cornacchione, P.; Siebert, F.-A.; Tagliaferri, L.; et al. Multilayer intensity modulated contact interventional radiotherapy (brachytherapy): Stretching the therapeutic window in skin cancer. *J. Contemp. Brachytherapy* **2023**, *15*, 220–223. [[CrossRef](#)] [[PubMed](#)]
51. Malik, N.; Yacoub, I.; Hsieh, K.; Choi, J.I.; Chhabra, A.; Simone, C.B. Radiotherapeutic Modalities and Advancements in the Treatment of Cutaneous Malignancies. *J. Clin. Med.* **2025**, *14*, 6547. [[CrossRef](#)] [[PubMed](#)]

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