Beyond MU Checks: IMSure 3D™ with SciMoCa™ for Independent Second Dose Check

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Volumetric Monte Carlo verification & independent commissioning to improve QA confidence

1 Introduction

Over the past decade, quality assurance (QA) in radiation therapy has undergone a profound transformation. Clinical techniques have evolved from relatively simple plans to highly modulated workflows—IMRT, VMAT, SRS—to the latest applications of online adaptive radiation therapy. At the same time, verification methods have also had to change: Monitor Unit (MU) checks and spot dose verifications, once sufficient, are no longer adequate to detect all sources of uncertainty and risk inherent in modern plans. The independent secondary dose check (ISDC) remains a key element of the QA process, but it must evolve to meet new clinical needs.

This white paper aims to illustrate the importance and necessity of integrating IMSure 3D™ as an independent secondary dose calculation solution for patient-specific verification. IMSure 3D™ is based on a Monte Carlo engine (SciMoCa™), independent of the TPS, and is not limited to point evaluations or 2D fluence maps: it simulates the transport of millions of particles in the patient's CT reconstruction and provides a 3D volumetric dose map. In this paper, we will explain the clinical and operational advantages of this approach, the validation and commissioning methods, and a practical path for adoption by centers that currently use point checks such as IMSure QA™ Software.

1.1 Risks and complexities introduced by advanced techniques

The introduction of technologies such as IMRT and VMAT has made it possible to concentrate radiation dose more precisely on the target volumes and spare healthy tissue. However, this complexity also increases the sensitivity of the treatment to small errors in modelling, data acquisition, or human input: errors in depth dose curve (DDC), beam profiles, MLC settings, output factor values, or improper Hounsfield to density conversions can produce significant discrepancies with respect to the dose actually delivered. Such errors can affect both the plan itself (choice of segments, modulation, and MLC sequence) and the quality of the data entered into the TPS (inconsistent or poorly performed commissioning measurements). The result is that highly modulated plans and small fields, as well as scenarios with marked heterogeneity (lungs, cavities), require verification tools that go beyond simple numerical comparison of MU or measurements at single points.

Note: guidelines and best practice documents (e.g., AAPM TG-219 [1] and related documents) reiterate the importance of a multiple approach to patient-specific QA, including both physical measurements and independent calculation checks.

1.2 Why phantom measurements are not enough

Pre-treatment measurements (phantom ionization chambers, films, 2D/3D arrays) remain essential for detecting hardware problems, such as collimator malfunctions, incorrect MLC calibrations, or physical beam discrepancies. However, these checks have inherent limitations:

- They are performed in fixed phantom geometries and therefore do not reflect the anatomical heterogeneity of the patient
- They do not provide an independent comparison of the dose calculation within the patient's CT scan: therefore, they do not detect errors related to the interpretation of tissue density or Hounsfield to density conversion errors
- They may not be feasible in online adaptive radiotherapy scenarios or in contexts where it is not possible to measure the plan before treating the patient.

For these reasons, relying solely on pre-treatment measurements does not guarantee complete risk coverage: these measurements must be accompanied by independent calculation checks capable of evaluating the plan in the patient's actual geometry and providing directly interpretable volumetric outputs and clinical metrics (e.g., DVH, voxel-wise differences, 3D gamma maps).

2 IMSure 3D™: an independent secondary check based on Monte Carlo

In light of the considerations expressed in the introduction, it is clear that traditional controls must be supplemented by an independent secondary dose check (ISDC) of the dose/MU as a structural element of the QA process for clinical plans. The operational effectiveness of this check depends directly on its accuracy: a useful ISDC must provide a calculation quality that is at least comparable—and preferably superior in terms of physical fidelity—to that of the TPS in use, because the discrepancies that the ISDC is called upon to report are precisely those that emerge from the comparison with the TPS.

IMSure 3D™ was created with the specific intent of providing this independent secondary verification. It is a software solution consisting of a calculation engine (SciMoCa™) and an analysis/visualization platform (GUI) that allows volumetric verification of plans in the patient's CT geometry. The main features and operational advantages introduced by the system are listed below.

Key features

- Monte Carlo engine (SciMoCa™): IMSure 3D™ uses SciMoCa™, a stand-alone Monte Carlo code for photons and electrons. SciMoCa™ is not a “clone” of other TPS/MC codes: it is an independent engine developed to provide clinically accurate dose calculations as a second check tool.
- Code independence: SciMoCa™ is a stand-alone MC engine. This independence is a key element for the ISDC function, as it reduces the risk of biases shared with the TPS.
- 3D volumetric verification: the system recalculates the dose in the patient's CT and produces voxel-wise dose maps and DVHs for all contoured structures.
- 3D gamma analysis and clinical metrics: IMSure 3D™ provides volumetric gamma analysis (3D gamma), DVH comparisons with summary statistics, and PDF reports ready for clinical audits.
- Integrated DICOM viewer: slice-by-slice visualization of the TPS vs. IMSure 3D™ dose and the corresponding gamma map directly on the patient's CT, facilitating qualitative and quantitative examination of disagreements.
- Clarity on statistical uncertainty: the Monte Carlo calculation provides, for each voxel, an estimate of the dose and the corresponding statistical uncertainty (σ). The software displays uncertainty maps in order to distinguish sampling noise from systematic discrepancies.
- CPU-based implementation: SciMoCa™ is optimized for multi-core CPUs; this choice increases portability and predictability compared to GPU-centric solutions and simplifies integration into clinical environments with heterogeneous IT infrastructures.

- Broad support for treatment platforms: IMSure 3D™ supports mainstream vendors and platforms—for example, Varian (including Halcyon), Elekta (including Unity), Siemens, CyberKnife, TomoTherapy, ZAP — making it suitable for departments with mixed machine types or vendors.
- Key strengths: physical accuracy (Monte Carlo) and operational speed (CPU-optimized calculations) are the two elements that characterize the clinical value of the software.

Numerous publications have validated and documented the scientific robustness of the SciMoCa™ engine (see Refs 2-17)

Notes on Monte Carlo interpretation

It is important to emphasize that the Monte Carlo algorithm does not provide "exact values", but statistical estimates of the voxel-wise dose: each voxel is associated with a standard deviation derived from the sampling process. For a correct clinical interpretation, it is necessary to consider both the magnitude of the observed dose difference (TPS vs. IMSure 3D™) and the statistical uncertainty on the voxel or on the aggregate metrics (DVH). IMSure 3D™ displays uncertainty maps and allows confidence intervals for DVH metrics to be evaluated, reducing the risk of interpreting deviations that are compatible with statistical noise as relevant.

2.1 Accuracy: what it means and implications for sensitivity and specificity

The accuracy of the ISDC is the critical factor that determines its clinical usefulness: greater physical fidelity in modelling leads to two related and complementary benefits:

- Increased sensitivity: the ability to detect truly incorrect plans (true positives)
- Increased specificity: the ability to avoid flagging plans that are actually correct as incorrect (reduction in false negatives)

Mechanism: An algorithm that more accurately reproduces particle transport and the effect of heterogeneity produces dose estimates that are closer to the "actual" dose delivered. This reduces systematic bias in estimates and allows for a clearer separation of deviations caused by actual errors (e.g., input errors, manipulations, failures) from noise or algorithm approximations.

Practical evaluation: Since absolute clinical "truth" is often inaccessible, the measurement of sensitivity and specificity can be approached differently depending on the study. For example, a 2023 study used original plans and manipulated versions to directly measure true/false positives and construct ROC curves, demonstrating how a well-designed Monte Carlo verification achieves high levels of sensitivity and specificity [12]. Another study, conducted by Aarhus University and based on percentile analysis of clinical datasets, compared the accuracy obtained with SciMoCa™ using Custom Beam Models (CBM) to generic models and the Mobius analytical algorithm; again, the results confirm better dosimetric agreement and greater operational reliability for SciMoCa™ + CBM configurations [17].

Operational implication: Converging evidence indicates that the use of SciMoCa™ (IMSure 3D™), and in particular the adoption of correctly commissioned Custom Beam Models, allows departments to adopt more restrictive acceptance criteria without increasing the burden of false alarms. In practice, this translates into a greater ability to capture relevant TPS-related discrepancies and, at the same time, a reduction in the time that physicists must devote to investigating insignificant results.

For a department that already uses IMSure QA™ Software (point/analytical algorithm), switching to IMSure 3D™ with SciMoCa™ and, in particular, adopting correctly commissioned Custom Beam Models tends to increase the ability to identify real clinical problems and reduce the workload resulting from false alarms. In practical terms: the department will have greater confidence in decisions and fewer man-hours spent on QA investigations.

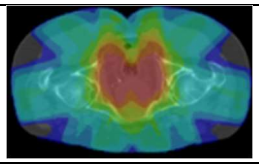
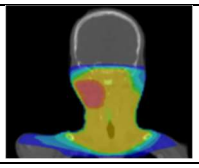
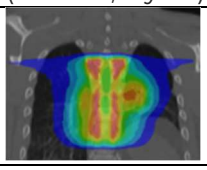
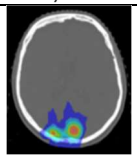
2.2 Calculation speed: determining factors and practical suggestions

Calculation speed is a crucial operational parameter because it determines the integration of the system into the clinical workflow, especially for on-table adaptive radiotherapy scenarios. The observed speed depends on several factors:

- Number of voxels/calculation grid size (grid resolution): the higher the resolution, the longer the calculation time.
- Statistical uncertainty target (σ target) or number of simulated histories: lower uncertainty requires more histories and increases the time.
- Plan topology: highly modulated plans or plans with many fields/arcs may take longer.
- Server hardware: the number of CPU cores, frequency, memory, and I/O have a decisive influence. IMSure 3D™ is optimized for multi-core CPU systems.
- Software settings (variance reduction, VSM, optimizations): proprietary techniques can reduce variance and improve throughput without sacrificing accuracy.

Table 1. shows a couple of examples of calculation times for different plan type, volumes and voxel size.

Table 1. Calculation times on 24-core Intel Core i9-14900; stat. MC-uncertainty 1%

Case	Prostate w. l. n.	Head & Neck	Multiple Mets (Verteb., Hylus)	Multiple Mets (brain)
				
Calc. Time	**27.0 sec**	**61.7 sec**	**51.1 sec**	**15.1 sec**
Plan Type	dMLC IMRT	VMAT	Tomotherapy	ZAP-X
Voxel size	3 mm	2 mm	2 mm	1 mm
PTV Volume	978.33 cc	860.9 cc	3 PTVs: 176.8 cc, 44.8cc, 26.0 cc	2 PTVs: 4.1 cc, 1.9 cc

2.3 Immediate implications

The introduction of a Monte Carlo-based ISDC (IMSure 3D™/SciMoCa™) overcomes the limitations of traditional controls by providing volumetric verification directly in the patient's CT scan. This allows for more stringent acceptance criteria without increasing false alarms and makes the workflow more efficient—an essential requirement for supporting on-table adaptive radiotherapy workflows [15,16].

3 Beam Model

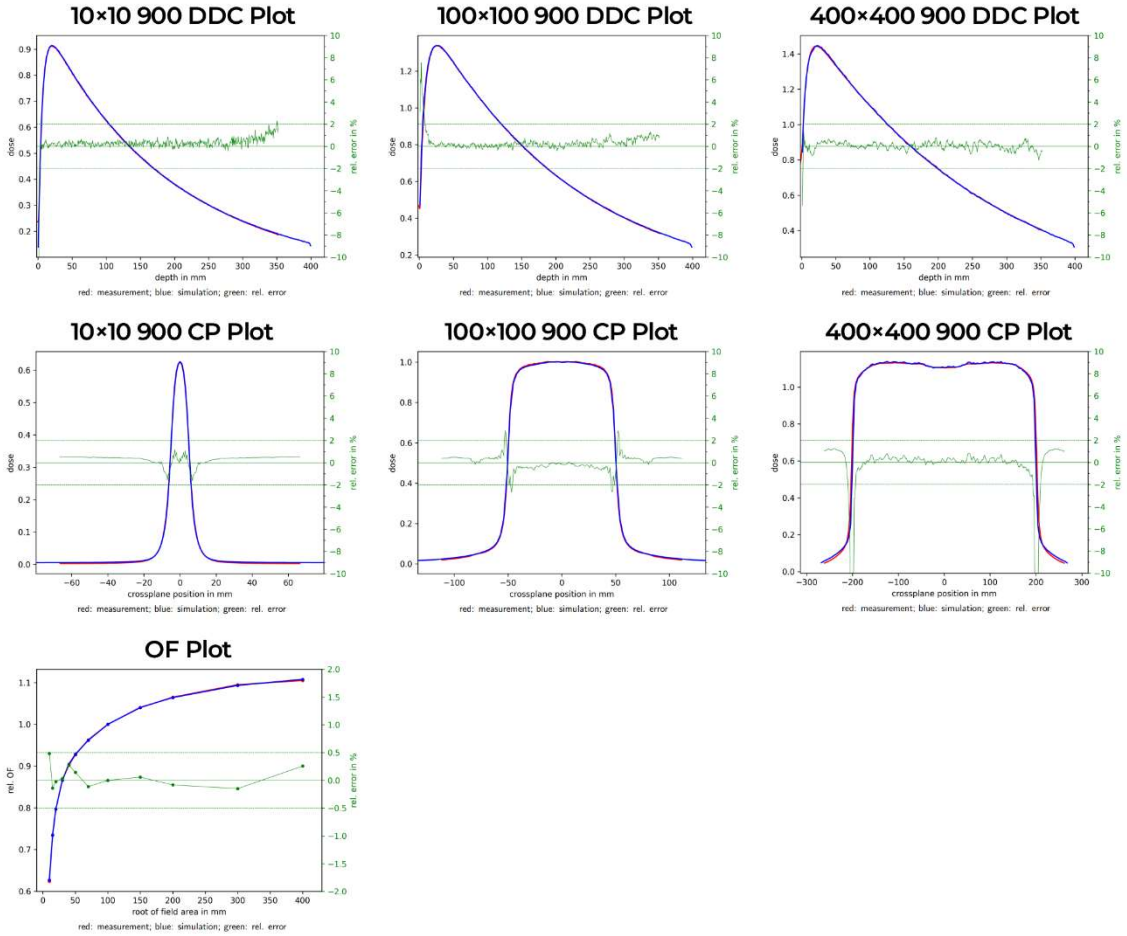
IMSure 3D™ supports three distinct types of Beam Models (BM), designed to meet the different needs of clinical centers:

- Generic Beam Models (Generic BM): standardized models intended for families of linacs with comparable beam quality
- Golden Beam Models (GBM): models built on reference datasets provided by the manufacturer (“golden” measurements representative of the machine model sold)
- Custom Beam Models (CBM): models built specifically on the basis of measurements provided by the individual facility. They represent the highest level of fidelity.

3.1 Custom Beam Models: Benefits and Diagnostic Role

Custom Beam Models (CBMs), being built on local site data, offer maximum fidelity for the specific beam behaviour of the machine (Fig.2). In addition to improving the dosimetric correspondence between independent recalculation and the actual clinical situation, the CBM fitting process performs a diagnostic function: when the model is unable to simultaneously reproduce the different measurements with the same set of physical parameters, indications of inconsistency in the data emerge (Fig.3).

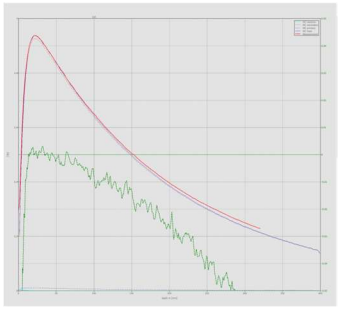
Fig.2: Measured DDCs, cross-plane profiles, and Output Factors (OFs) (red) overlaid with SciMoCa™ simulations (blue) for multiple field sizes. The close agreement and low residual differences (green) demonstrate a high-fidelity beam model and high-quality commissioning data, validating the CBM performance across field geometries.



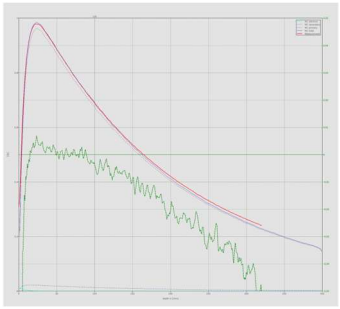
In practice, fitting highlights which measurements or data sets are inconsistent (e.g., DDC or profiles that are not compatible with each other), providing the department with independent feedback that is useful for undertaking targeted checks. This diagnostic value increases the overall quality of commissioning, improves confidence in TPS vs. ISDC comparisons, and helps reduce false positives due to low-quality modelling.

In Fig.2 and Fig.3 two commissioning datasets are examined: one from a 15MV linac showing excellent agreement with SciMoCa™ simulations, and one from a 10MV dataset where the CBM fitting revealed inconsistencies in the measurement set.

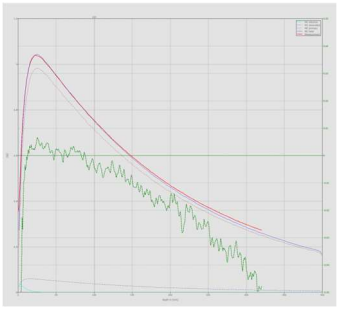
Fig.3: Output from the CBM fitting process showing a set of measurements that cannot be reproduced simultaneously. Measured DDCs (red) versus SciMoCa™ simulations (blue) for multiple fields: excellent match at 100x100 mm but clear, systematic disagreement at smaller and larger field sizes. This pattern indicates a measurement inconsistency in the dataset (e.g., detector or electrometer issue). The CBM diagnostic therefore identifies which specific measurements are not self-consistent and suggests targeted re-measurements before TPS commissioning.



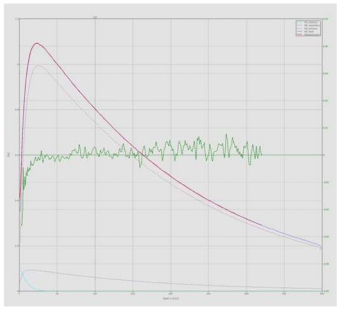
20x20 mm



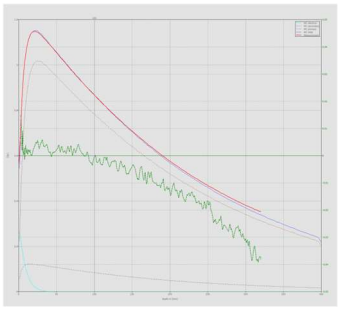
30x30 mm



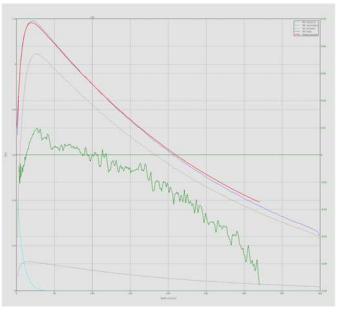
60x60 mm



100x100 mm



200x200 mm



400x400 mm

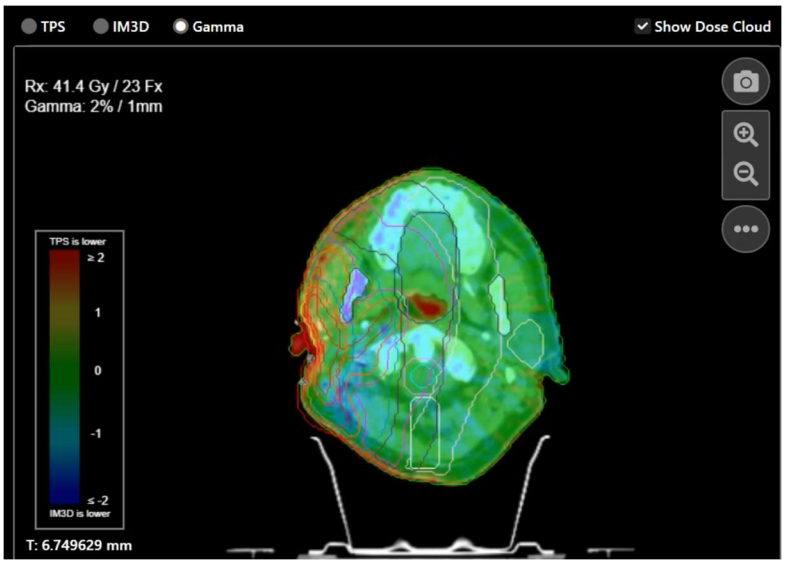
3.2 Advantages of Monte Carlo simulations compared to other algorithms

Monte Carlo simulations offer structural characteristics that make them particularly suitable as a basis for an Independent Second Dose Check:

- Physical parameters and consistency: the source and model parameters have physical meaning and apply to different collimation settings. This promotes consistency and reproducibility: a model that is valid for one field remains valid for similar fields without the need for non-physical local adjustments.
- Diagnostic capability: since the MC model is based on a simple and generalizable physical representation, the fitting process does not easily "mask" inconsistent measurements; on the contrary, it brings them to light.
- Robustness in heterogeneity and small sizes: MC correctly handles scattering, heterogeneity, and small-field effects, making it more reliable in complex scenarios (lungs, cavities, SRS/SBRT) than analytical or point algorithms (Fig.4)

The combined use of an independent Monte Carlo engine (SciMoCa™) and appropriate Beam Models (in particular CBM when available) not only improves the accuracy of the recalculation but also provides a diagnostic tool for the quality of commissioning measurements, increasing the specificity of secondary control and reducing the workload associated with false alarms.

Fig.4: Axial CT slice with overlaid percent dose-difference map between TPS (in this case analytical algorithm) and IMSure 3D™. The figure highlights anatomically localized, clinically relevant discrepancies that can affect OAR/PTV metrics.



4 Conclusion

IMSure 3D™, based on the SciMoCa™ Monte Carlo engine, offers independent secondary dose control with a level of accuracy equal to or greater than that of the TPS. Unlike analytical algorithms, it simulates particle transport on the patient's actual CT scan, producing a volumetric dose map that takes heterogeneity into account with maximum fidelity.

Combining accuracy and speed, IMSure 3D™ reduces false alarms while maintaining high sensitivity to actual planning errors, lightening the physicist's workload and strengthening clinical decisions. The availability of Custom Beam Models further improves reliability by providing an independent audit of commissioning data and ensuring consistency with physical reality.

In the era of advanced techniques and adaptive radiotherapy, where time is limited and accuracy is non-negotiable, IMSure 3D™ fills the gaps left by traditional QA and sets a new standard for independent secondary dose checks.

5 References

1. Zhu TC, Stathakis S, Clark JR, Feng W, Georg D, Holmes SM, Kry SF, Ma CM, Miften M, Mihailidis D, Moran JM, Papanikolaou N, Poppe B, Xiao Y. ***Report of AAPM Task Group 219 on independent calculation-based dose/MU verification for IMRT.*** Med.Phys.2021 June; 48:e808–e829.
2. Hoffmann L, Alber M, Söhn M, Elstrøm UV. ***Validation of the Acuros XB dose calculation algorithm versus Monte Carlo for clinical treatment plans.*** Med Phys. 2018 Aug;45(8):3909–3915.
3. Milder MTW, Alber M, Söhn M, Hoogeman MS. ***Commissioning and clinical implementation of the first commercial independent Monte Carlo 3D dose calculation to replace CyberKnife M6™ patient-specific QA measurements.*** J Appl Clin Med Phys. 2020 Nov;21(11):304–311.
4. Piffer S, Casati M, Marrazzo L, Arilli C, Calusi S, Desideri I, Fusi F, Pallotta S, Talamonti C. ***Validation of a secondary dose check tool against Monte Carlo and analytical clinical dose calculation algorithms in VMAT.*** J Appl Clin Med Phys. 2021 Apr;22(4):52–62.
5. Szeverinski P, Kowatsch M, Künzler T, Mainschad M, Clemens P, DeVries AF. ***Evaluation of 4-Hz log files and secondary Monte Carlo dose calculation as patient-specific quality assurance for VMAT prostate plans.*** J Appl Clin Med Phys. 2021 Jul;22(7):235–244.
6. Shen Z, Tan X, Li S, Tian X, Luo H, Wang Y, Jin F. ***Correlation between the γ passing rates of IMRT plans and the volumes of air cavities and bony structures in head and neck cancer.*** Radiat Oncol 2021 Jul;16:134
7. Lay LM, Chuang K-C, Wu Y, Giles W, Adamson J. ***Virtual patient-specific QA with DVH-based metrics.*** JACMP 2022 May;23(11):e13639
8. Milder MTW, Magallon-Baro A, den Toom W, de Klerck E, Luthart L, Nuyttens JJ, Hoogeman MS. ***Technical feasibility of online adaptive stereotactic treatments in the abdomen on a robotic radiosurgery system.*** phiRO 2022 July;23:103-108
9. Muacevic A, Eder MM, Hofmann T, Fürweger C, Ehret F. ***Self-Shielding Gyroscopic Radiosurgery — A First Clinical Experience, Case Series, and Dosimetric Comparison.*** World Neurosurgery 2022 August;164:e420-e426
10. Kucukmorkoc E, Kucuk N, Sanlı E, Celebi S, Caglar HB, Ozturk ST. ***Investigation of Dose Thresholds and Normalization Methods Effect on Gamma Index Analysis for SRT and SBRT Patients with a Monte Carlo Secondary Dose Check Software.*** J Med Biol Eng. 2023 May.
11. Adamson J, Erickson BG, Wang C, Cui Y, Alber M, Kirkpatrick J, Yin F-F. ***Generation, validation, and benchmarking of a commercial independent Monte Carlo calculation beam model for multi-target SRS.*** Z Med Phys 2023 Sept, In Press
12. Kowatsch M, Szeverinski P, Clemens P, Künzler T, Söhn M, Alber M. ***Sensitivity and specificity of Monte Carlo based independent secondary dose computation for detecting modulation-related dose errors in intensity modulated radiotherapy.*** Z Med Phys 2023 Oct, In Press

13. Erickson B, Cui Y, Alber M, Wang C, Yin F, Kirkpatrick J, Adamson J. ***Independent Monte Carlo dose calculation identifies single isocenter multi-target radiosurgery targets most likely to fail pre-treatment measurement.*** JACMP 2024, e14290
14. Li S, Luo H, Tan X, Qiu T, Yang X, Feng B, Chen L, Wang Y, Jin F. ***The impact of plan complexity on calculation and measurement-based pre-treatment verifications for sliding-window intensity-modulated radiotherapy.*** phiRO 2024 July; 31: 100622
15. Brand VJ, Milder MTW, Christianen MEMC, de Vries KC, Hoogeman MS, Incrocci L, Froklage FE. ***First-in-men online adaptive robotic stereotactic body radiotherapy: Towards ultra-hypofractionation for high-risk prostate cancer patients*** Advanced in Radiation Oncology 2024; 101701
16. Ruggieri R, Bianchi N, Gurrera D, Naccarato S, Borghese RF, De Simone A, Sicignano G, Stavrev P, Stavreva N, Pellegrini R, Rigo M, Ricchetti F, Nicosia L, Giaj-Levra N, Pastorello E, Allegra A, De-Colle C, Alongi F. ***Validation of a Monte Carlo-based dose calculation engine including the 1.5 T magnetic field for independent dose-check in MRgRT.*** Physica Medica 130 (2025) 10496
17. Hoffmann L, Linaa MB, Møller DS. ***Independent secondary dose calculation for patient-specific quality assurance: Quantitative benefit of Monte–Carlo and custom beam modelling.*** J Appl Clin Med Phys. 2025;26:e70265.