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Original Research Article

A multinational audit of small field output factors calculated by treatment planning systems used in radiotherapy

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ABSTRACT

Background and purpose: An audit methodology for verifying the implementation of output factors (OFs) of small fields in treatment planning systems (TPSs) used in radiotherapy was developed and tested through a multinational research group and performed on a national level in five different countries.

Materials and methods: Centres participating in this study were asked to provide OFs calculated by their TPSs for 10 × 10 cm^2, 6 × 6 cm^2, 4 × 4 cm^2, 3 × 3 cm^2 and 2 × 2 cm^2 field sizes using an SSD of 100 cm. The ratio of these calculated OFs to reference OFs was analysed. The action limit was ± 3% for the 2 × 2 cm^2 field and ± 2% for all other fields.

Results: OFs for more than 200 different beams were collected in total. On average, the OFs for small fields calculated by TPSs were generally larger than measured reference data. These deviations increased with decreasing field size. On a national level, 30% and 31% of the calculated OFs of the 2 × 2 cm^2 field exceeded the action limit of 3% for nominal beam energies of 6 MV and for nominal beam energies higher than 6 MV, respectively.

Conclusion: Modern TPS beam models generally overestimate the OFs for small fields. The verification of calculated small field OFs is a vital step and should be included when commissioning a TPS. The methodology outlined in this study can be used to identify potential discrepancies in clinical beam models.

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1. Introduction

The challenges of small field dosimetry in photon beams have been investigated for more than two decades [1,2] and gained importance with the implementation of advanced treatment techniques such as intensity modulated radiotherapy (IMRT), stereotactic (body) radiotherapy (SBRT) and stereotactic radiosurgery (SRS). The main issues in accurate determination of field OFs in these beams are the loss of lateral charged particle equilibrium and source occlusion, as well as detector related effects such as volume averaging and the difference between the density of the detector material and water [3–9]. In 2008, Alfonso et al. introduced a formalism on the determination of small field OFs using detector and field size specific correction factors [10]. Several research groups have investigated these factors for a wide range of passive and active detectors [7,11–15]. Recently, a new code of practice on small static fields used in external beam radiotherapy has been published [16].

Accurate experimental determination of OFs in small fields is only one component of the TPS to calculate the dose correctly. The other part is the implementation or modelling of these OFs in a TPS, which is critical for the dose calculation accuracy. Dose calculation algorithms have evolved from simple factor based dose calculation as found in [17,18], to model-based algorithms [3,19–22], stochastic linear Boltzmann transport equation solvers such as Monte Carlo algorithms [23], and deterministic linear Boltzmann transport equation solvers [24,25]. These model-based algorithms rely on an accurate source model describing the energy fluence entering the patient for a given aperture. Source models are usually optimized based on basic beam data provided by the user. For the optimization of small field OFs, e.g. for an accurate modelling of the penumbra, the aforementioned effects in small fields have to be considered. It is expected that the accuracy of source models for small fields will increase with improvements in the measurement accuracy of small fields accounting for ion chamber and fluence corrections [3], provided that manufacturers are willing to optimize their source models for small fields. However, small field calculations for TPSs are usually not the focus of standard commissioning procedures and therefore may be prone to errors.

National and international organizations have provided recommendations on acceptance testing, commissioning and quality assurance of medical TPSs [26–28]. These documents outline the individual steps in validating the general functionality of the TPS and especially dose calculation accuracy. All of these documents recommend the verification of OFs by recalculation and comparison against measurements as OFs have a direct impact on the number of monitor units necessary to deliver the prescribed dose. E.g. TECDOC-1583 suggests the comparison of calculated and measured OFs for field sizes ranging from $3 \times 3\,\text{cm}^2$ to $40 \times 40\,\text{cm}^2$ using a tolerance of ± 2% [27]. A comprehensive data set on small field OFs of various treatment machines produced by different vendors has been determined by the Imaging and Radiation Oncology Core Houston QA Centre (IROC-Houston QA Centre, formerly the Radiological Physics Centre). OFs were measured for field sizes down to $2 \times 2\,\text{cm}^2$ at a depth of 10 cm in water at 100 cm SSD on more than 150 linear accelerators as a part of the on-site visits. These measurements were made using a cylindrical ionization chamber. The measured OFs were grouped according to energy and linear accelerator manufacturer. Even when grouped across multiple accelerator models, the measured OFs were highly consistent for a given energy and manufacturer. The average standard deviation of the output factor for a given manufacturer and energy was less than 0.5% except for the $2 \times 2\,\text{cm}^2$ fields which was 0.7%, indicating that the reference OFs were highly consistent and descriptive of the linacs. Besides that, average differences between calculated and measured output factors for the $2 \times 2\,\text{cm}^2$ field ranging from 1.3% to 5.8% depending on the linac vendor and beam energy were observed [29,30].

A coordinated research project was launched to develop audit methodologies for testing the implementation of treatment techniques with different complexities. The aim of this project was to make these methodologies available to national external audit groups and assist them with the local development of these audits. In particular, dosimetry audit of small fields was of interest because of the prevalence of difficulties both in conducting small field dose measurements as well as in computing them. One contributing factor to observed errors with small fields is the agreement between calculated and measured lateral small beam profiles. Discrepancies of more than 3 mm have been observed which could potentially lead to an unsatisfactory accuracy in dose calculation of advanced treatment techniques [31]. Another aspect is the accuracy of calculated small field output factors (OFs) using treatment planning systems (TPSs) employed in clinical practice, which is focus of this work.

The results of this audit, which was designed within a multinational coordinated research project, tested with national audit groups in a multi-centre setting and implemented on a national level in a few countries, are given.

2. Materials and methods

2.1. Audit development

A simple dose calculation exercise was designed by a group of IAEA consultants to assess the TPS model accuracy of small field OFs. A multicentre study was initiated to validate the audit procedure, clarity of instructions and completeness of the reporting form. The exercise was performed among all of the centres participating in the IAEA coordinated research project. They tested the methodology in their institutions in order to demonstrate the feasibility of implementing this audit on a national level within their countries. A total of 17 institutions in 14 countries (Algeria, Brazil, China, Cuba, Czech Republic, India, Poland, Thailand, Austria, Belgium, Finland, Sweden, UK, and USA) participated together in the multicentre phase of this audit. The participating institutions were considered as centres of excellence in this field. Finally, this audit was performed on a national level in Brazil, China, Czech Republic, India and Poland obtaining results from a total of 103 institutions. A summary of the treatment machine manufacturers and models involved in this project is provided in Table 1.

Table 1
Summary of treatment machines grouped by manufacturer and model.

Audit run	Linac Manufacturer	Linac Model	Number of Linacs	Nominal beam energies [MV]
Multicentre run				
	Varian	Clinac	8	6, 15, 18
		TrueBeam	2	6
		Trilogy	1	6
		Novalis STx	2	6, 15
		TrueBeam STx	3	6, 15
	Elekta	Synergy	5	6, 10
		Precise	1	6
	Siemens	Primus	1	6
National runs				
	Varian	Clinac	59	6, 10, 15, 18, 20
		TrueBeam	16	6, 10, 15, 20
		Trilogy	11	6, 10
		Novalis STx	4	6, 15
		TrueBeam STx	4	6, 10, 15
		Unique	6	6
	Elekta	Synergy	47	6, 10, 15, 18
		Precise	7	6
		Axesse	2	6
		Versa HD	1	6
	Siemens	Artiste	17	6, 15
		Primus	5	6
		Oncor	4	6