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TECSAN Review

DoRGaN: Development of Quality Assurance and Quality Control Systems for High Dose Rate Brachytherapy Based on GaN Dosimetry Probes

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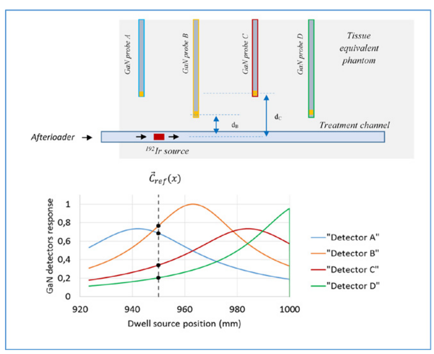
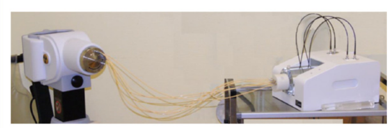
Highlights

- An instrumented phantom for QA in HDR Brachytherapy has been designed and tested.
- An instrumented gynecological applicator has also been developed for QC in HDR-BT.
- Both systems implements 4 GaN-based dosimeter probes.
- These systems are compared with the state of the art.

Graphical abstract





Instrumented phantom for QA in HDR Brachytherapy

Abstract

Background: Safe High Dose Rate Brachytherapy (HDR-BT) requires quality assurance/quality control (QA/QC) according to IPEM and ESTRO recommendations. Recent advances in real-time dosimetry and related developments of QA, QC and in vivo dosimetry (IVD) systems have offered new possibilities for effective independent treatment verification, and thus for improving the patient safety.

Contributions: This paper briefly reports the state of the art of different QA and QC approaches and systems. It also presents our related studies, carried out within the framework of DoRGaN research project, which have led to two proposed instruments: a QA pretreatment instrumented phantom and a QC gynecological applicator. Both systems implement a real-time dwell-source distance-measuring approach using multiple Gallium Nitride (GaN) dosimetry probes. First prototypes have been designed and tested. Their characteristics (including those of the employed GaN probes) are evaluated in comparison with the state of the art.

Conclusion: For developing systems for HDR-BT, the GaN probe has been shown to meet requirements for high sensitivity, high measurement rate, small response anisotropy and large dose measurement range. The proposed QA instrumented phantom has comparable or better characteristics when compared with diode-based and Al_2O_3:C-based systems. The other QC gynecological applicator has higher time and spatial resolutions than the state-of-the-art IVD systems, which proves that it is suitable for real-time monitoring of HDR-BT physical parameters.

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Keywords: GaN radioluminescent transducer; GaN dosimetry probe; Dwell-source distance-measuring approach; Quality Assurance (QA) pretreatment instrumented phantom; Quality Control (QC) gynecological applicator

1. Introduction

Brachytherapy has the advantage of delivering a very closely-targeted treatment with few secondary effects. It represents about 4% of radiotherapy treatments in France. HDR-BT has been progressing strongly since 2000 and today account for ∼50% of brachytherapy treatments [1]. HDR-BT is performed on an outpatient basis and thus is much more convenient and cost-effective than Low Dose Rate BT, which usually requires a hospital stay. HDR-BT has proven to be a successful treatment for cancers of the prostate, cervix, endometrium, breast, skin, bronchus, esophagus, head and neck and several other types of cancer [2].

HDR-BT implements small size, high activity isotope sources (370 GBq for ^{192}Ir and 75 GBq for ^{60}Co). It is a conformal therapy (with exponential dose decrease with increasing distance from the source) which permits, if required, dose escalation (∼20 Gy in one fraction for localized prostate cancers) [3,4].

Treatment parameters (including dwell times and dwell positions of the radioactive source calculated by treatment planning system) are transferred to the remote afterloading treatment system. This system should provide high precision control of the movement of the radioactive source in the treatment channels for safe and efficient treatment delivery. In particular, it is of key importance for optimal employments of target dose escalation and organ-at-risk (OAR) dose minimization protocols.

Treatment errors in BT are categorized into human errors (e.g. incorrectly specified source strength, erroneously connected source transfer guide tubes and applicator reconstruction errors) or malfunctions of the equipment (e.g. defective afterloader stepping motor and flaws in the control software) [5]. Safe HDR-BT treatments require quality assurance/quality control (QA/QC) which are currently implemented according to guideline given in IPEM Report 81 and/or ESTRO Booklet No. 8 [6–8]. Recent advances in real-time dosimetry and related developments of QA, QC and in vivo dosimetry (IVD) systems open the way for effective independent treatment verification and thus, improved patient safety during HDR-BT [5,9,10].

There are scientific and instrumental challenges in developing new QA, QC and in vivo dosimetry (IVD) systems. This paper briefly reports the state of the art of different approaches and systems and presents our studies leading to two proposed instruments: a QA pretreatment instrumented phantom and a QC gynecological applicator. Both systems implement a real-time dwell-source distance-measuring approach using multiple GaN dosimetry probes. Each probe was fabricated using a radioluminescent (RL) Gallium Nitride (GaN) transducer, and RL is transmitted through optical fiber connection to an optical signal detection module. Both systems have been designed, fabricated and tested, including testing in clinical conditions. These studies were carried out within the framework of an ANR research-funded project, called DoRGaN.

Table 1
ESTRO recommendations for HDR afterloader QA [7].

Physical parameter	Verification frequency	Acceptance level
Source strength	Source exchange	<5%
Dwell Source position	Daily	<2 mm
Length of treatment tubes	Annual	<1 mm
Irradiation timer	Annual	<1%

Our studies included different characterizations of GaN transducer and GaN dosimetry probe for optimal design. The main characteristics of the GaN dosimetry probe are reviewed against the state-of-the-art real-time HDR-BT dosimetry technology. Our two proposed QA and QC systems are then compared to QA, QC and IVD systems recently proposed in the literature.

2. Challenges for HDR-BT dosimetry

The main recommendations of ESTRO for monitoring/verifying physical parameters of the treatment are summarized in Table 1.

To meet such requirements in developing HDR-BT QA/QC systems, there are several practical challenges with specific issues for detectors and associated instrumentation [5,9].

HDR-BT is a dynamic therapy where the irradiation conditions at a given location change during the treatment delivery. Thus, it requires real time detectors and instrumentation for a continuous monitoring of the irradiation. A large dynamic range of measurement is also needed since the measured dose rate depending on Source-Detector Distance (SDD) varies in a large amount during the treatment. For instance, the dose rate received by the detector is divided by a factor ∼50 when SDD changes from 1 cm to 7 cm (the dose rate is ∼7 Gy·min^{-1} for SDD = 1 cm with HDR ^{192}Ir source) [11]. Thus, instrumentation for HDR-BT requires real-time detectors with linear response to a large dynamic range of dose rates.

Irradiation incidence changes also a lot during the treatment. Considering a detector placed at 20 mm from the treatment channel, the irradiation incidence angle can vary ranging [0°, 79°] for a source displacement of 10 cm. Detectors with low response anisotropy should be employed.

Another major challenge for detectors comes from the change of local irradiation spectrum with SDD. For this concern and for ensuring accuracy of dosimetric measurements, there are preferable considerations on choosing tissue-equivalent detectors whose responses have low-energy dependence. However, there are also more compact and sensitive detectors that deserve to be considered (also for the reason below) if their responses can be compensated so as to meet accuracy requirements.