Dozimetrie EPR în radioterapie: dozimetre din alanină, format de Li și alte sisteme

Dozimetria radiaţiilor, protecţia personalului şi a pacienţilor este o activitate esenţială a fizicienilor medicali.

Pentru dozimetria radiaţiilor pot fi folosiţi detectori standard sau aceasta poate fi efectuată prin măsurarea radicalilor liberi produşi în diferite sisteme moleculere.

Pentru pregătirea de specialitate a fizicienilor medicali, dar şi pentru identificarea unor teme actuale pentru competiţia de proiecte şi pentru activitatea de devoltarea durabilă pentru fizicienii medicali sunt necesare documentaţii detaliate în literatura de specialitate cu scopul de a identifica metode simple de măsurarea a dozelor de radiaţii, indirect, prin intermediul semnalului RES datorat radicalilor liberi induşi în diferite sisteme moleculare.

In acest sens am elaborat o documentare detaliată din literatura de specialitate în scopul identificării celor mai recente preocupări ştiintifice referitoare dozimetria radiaţiilor folosind tehnica EPR (Electron Paramagnetic Resonance) cu sisteme simple şi necostisitoare.

In acest document raportăm o serie de articole ştiinţifice noi, publicate în literatura de specialitate, referitoare la folosirea dozimetriei EPR bazată pe radicalii liberi induşi de către radiaţia X sau gama în alanină sau formatul de litiu. Aceste articole vor fi puse la dispoziţia studenţilor pe canalele de comunicare on-line (platform Teams, site-ul proiectului).

Documentul este organizat în felul următor:

1. datele de identificare a articolelor (autori, titlu, anul apariţiei, volum, pagina de început şi sfârşit/numărul articolului, adresa DOI.
2. abstractul articolului
3. concluziile articolului

Lista articolelor propuse

Articol 1

1. G. Mierzwińska, B. Michalec, I. Ogłodek, B. Petelenz, M.P.R. Waligórski, Alanine/EPR Dosimetry as a Potential Tool for Quality Assurance in Proton Beam Radiotherapy, Romanian Reports in Physics, 2014, 66, 54-60. doi: indisponibil

Abstract

ALANINE/EPR DOSIMETRY AS A POTENTIAL TOOL FOR QUALITY ASSURANCE IN PROTON BEAM RADIOTHERAPY*

G. MIERZWIŃSKA[1], B. MICHALEC[1], I. OGŁODEK[2], B. PETELENZ[1], M.P.R. WALIGÓRSKI[1]

[1]The "Henryk Niewodniczański" Institute of Nuclear Physics, Polish Academy of Sciences, ul. Radzikowskiego 152, 31-342 Kraków, Poland, E-mail: Gabriela.Mierzwinska@ifj.edu.pl
[2] Jagiellonian University, Institute of Physics, ul. Reymonta 4, 30-059 Kraków, Poland

Received April 23, 2013

Abstract. Free-radical, alanine/EPR dosimetry can be applied to measure beam doses and cumulative doses delivered to the target volume in proton beam radiotherapy, as a supplementary part of the Quality Assurance program of the proton ocular radiotherapy procedure at the Institute of Nuclear Physics (IFJ PAN). Development of suitable characteristics of the alanine dosimeter and the principle of application of this detector in proton beam radiotherapy are described.

Key words: alanine, electron paramagnetic resonance, proton radiotherapy, quality assurance system.

Concluzii

5. SUMMARY AND CONCLUSIONS

In this study we confirmed the applicability of the alanine detector as a potential element of the Quality Assurance system of patient and ion beam dosimetry in proton radiotherapy. The main advantages of alanine: linearity of dose response over the therapeutic range, lack of dependence of relative efficiency (with respect to Co-60 reference γ-rays) over the region of extended Bragg peak and ability to measure doses received by the patient in a cumulative fashion, make alanine a promising detector for QA purposes in clinical proton radiotherapy. We expect to be able to produce our own alanine detectors which would best suit our specific needs in terms of size and mechanical stability.

In suitable conditions (dark and dry storage) the radiation-induced signal in alanine is stable, thus the irradiated detector can serve as additional documentation of the patient's exposure over the therapy course. This signal can be measured repeatedly since the read-out procedure does not affect (or destroy) the signal. It is then possible to re-assess patient exposures at any time after completing the course of their radiotherapy, *e.g.* for verification, control or research purposes.

We are planning to use alanine in proton beam dosimetry and for patient dosimetry. Alanine detectors will be then irradiated in the proton beam prior to treating the patient and also in the part of beam directed at the target volume which is not modified by the individual collimator, as a form of *in vivo* dosimetry (the detector cannot be placed directly in the part of the beam which irradiates the target volume, as it would interfere with the planned dose distribution in the tumour volume). Most likely, the alanine detector will be placed inside the individual brass collimator and be read out following each radiotherapy session (fraction) to verify the dose received by the target volume, in cumulative fashion. Work on this stage of the project of applying the alanine detector for Quality Assurance in proton radiotherapy is under way [12].

Articol 2

2. Harold M. Swartz, Benjamin B. Williams, Bassem I. Zaki, Alan C. Hartford, Lesley A. Jarvis, Eunice Y. Chen, Richard J. Comi, Marc S. Ernstoff, Huagang Hou, Nadeem Khan, Steven G. Swarts, Ann B. Flood, Periannan Kuppusamy, Clinical EPR - Unique Opportunities and Some Challenges, Academic Radiology, 2014, 21, 197-206 doi: http://dx.doi.org/10.1016/j.acra.2013.10.011

Abstract

Clinical EPR:

Unique Opportunities and Some Challenges

Harold M. Swartz, MD, PhD, MSPH, Benjamin B. Williams, PhD, Bassem I. Zaki, MD, Alan C. Hartford, MD, PhD, Lesley A. Jarvis, MD, PhD, Eunice Y. Chen, MD, PhD, Richard J. Comi, MD, Marc S. Ernstoff, MD, Huagang Hou, MD, Nadeem Khan, PhD, Steven G. Swarts, PhD, Ann B. Flood, PhD, Periannan Kuppusamy, PhD

Electron paramagnetic resonance (EPR) spectroscopy has been well established as a viable technique for measurement of free radicals and oxygen in biological systems, from in vitro cellular systems to in vivo small animal models of disease. However, the use of EPR in human subjects in the clinical setting, although attractive for a variety of important applications such as oxygen measurement, is challenged with several factors including the need for instrumentation customized for human subjects, probe, and regulatory constraints. This article describes the rationale and development of the first clinical EPR systems for two important clinical applications, namely, measurement of tissue oxygen (oximetry) and radiation dose (dosimetry) in humans. The clinical spectrometers operate at 1.2 GHz frequency and use surface-loop resonators capable of providing topical measurements up to 1 cm depth in tissues. Tissue pO_2 measurements can be carried out noninvasively and repeatedly after placement of an oxygen-sensitive paramagnetic material (currently India ink) at the site of interest. Our EPR dosimetry system is capable of measuring radiation-induced free radicals in the tooth of irradiated human subjects to determine the exposure dose. These developments offer potential opportunities for clinical dosimetry and oximetry, which include guiding therapy for individual patients with tumors or vascular disease by monitoring of tissue oxygenation. Further work is in progress to translate this unique technology to routine clinical practice.

Key Words: Electron paramagnetic resonance; free radical; oxygen; hyperoxygenation; tumor therapy; radiation therapy; dosimetry.

Concluzii

CONCLUSION

The recent developments in EPR instrumentation, probes, and methods offer potential opportunities for clinical oximetry and dosimetry. The EPR oximetry is valuable for guiding therapy for individual patients with tumors or vascular disease, by monitoring tissue oxygenation. Further work is in progress to translate this unique technology to routine clinical practice. The use of in vivo EPR dosimetry appears to be sufficient for the initial stage of triage in a large-scale radiation event, and further improvements are underway, consistent with the goal of becoming an intrinsic part of the response system within 2–3 years.

Articol 3

Barbara Michalec, Marta Ptaszkiewicz, Gabriela Mierzwinska, Joanna Dabrowska, Urszula Sowa, Renata Majgier, The comparison of the proton dose distribution calculated with the treatment planning system and measured with alanine detectors in the eye phantom irradiated under therapeutic conditions, Radiation Measurements, 2014, 71, 355-358. doi: http://dx.doi.org/10.1016/j.radmeas.2014.05.032

Abstract

Contents lists available at ScienceDirect

Radiation Measurements

journal homepage: www.elsevier.com/locate/radmeas

The comparison of the proton dose distribution calculated with the treatment planning system and measured with alanine detectors in the eye phantom irradiated under therapeutic conditions

Barbara Michalec*, Marta Ptaszkiewicz, Gabriela Mierzwińska, Joanna Dąbrowska, Urszula Sowa, Renata Majgier

Institute of Nuclear Physics Polish Academy of Science (IFJ PAN), ul. Radzikowskiego 152, PL 31-342 Krakow, Poland

HIGHLIGHTS

- We confirmed the utility of alanine for in-phantom measurements in proton beams.
- We compared TPS-planned and measured doses in proton eye radiotherapy simulation.
- We discovered the limitation of alanine in registration the high dose gradients.

ARTICLE INFO

Article history:
Available online 12 June 2014

Keywords:
Alanine
Proton radiotherapy
EPR dosimetry
Treatment planning
TPS
Ocular tumors

ABSTRACT

The paper describes the applicability of commercially available alanine detectors produced by Synergy Health for verification of the dose distribution calculated by the treatment planning system (TPS) used in proton eye radiotherapy – Eclipse Ocular Proton Planning (EOPP) program, version 8.9.06, Varian Medical Systems. The TPS-planned dose distribution at selected points in the eye phantom is compared to the dose registered by alanine detectors at these points during a simulated therapeutic irradiation at the proton eye radiotherapy facility in the Henryk Niewodniczanski Institute of Nuclear Physics (IFJ PAN), Krakow, Poland. The phantom was irradiated to obtain, a typical for choroidal melanoma, fraction dose of 15 CGE (13,64 Gy) at the tumor location. The dose registered with alanine pellets located inside the simulated tumor volume demonstrates a good agreement with the TPS-planned dose. The typical for proton radiotherapy, steep dose fall-off outside the treated area is registered by the alanine pellets however, it is difficult to assess it quantitatively, because the dose related EPR signal is registered from the entire pellet volume.

Concluzii

4. Conclusions

The alanine detectors produced by Synergy Health, calibrated in terms of dose to water, can be successfully applied for comparisons between the TPS-planned and measured dose distributions inside the target volume in the proton radiotherapy, particularly in the SOBP region. As is typical for proton radiotherapy, a steep dose fall-off outside the treated area is registered by the investigated alanine detectors; however, it is difficult to assess this fall-off quantitatively with pellets of this size. The dose-related EPR signal is measured from the entire pellet volume, which is too large compared to the distal fall-off area. The sharp dose gradient inside the pellet volume could be investigated using the EPR imaging technique, which combines a high spatial resolution with the specificity of EPR and would enable the spin density within the pellet to be determined.

The Synergy Health alanine detectors can also be used in other QA and QC procedures involving therapeutic proton beam, e.g., during commissioning or periodic tests of the beam or in dose delivery control (Michalec et al., 2013). The most substantial advantages of the alanine detectors in contrast to different types of passive dosimeters are their non-destructive read-out and low fading (Schauer et al., 2007; Ahlers and Schneider, 1991), making them a type of "dose archive" that maintains the dose record for documentation.

The investigated alanine detectors could most likely be widely applied for dose distribution measurements in conventional radiotherapy, which is characterized by much smaller dose gradients.

Articol 4

Emelie Adolfsson, Shane White, Guillaume Landry, Eva Lund1, Håkan Gustafsson, Frank Verhaegen, Brigitte Reniers, Åsa Carlsson Tedgren and Gudrun Alm Carlsson, Measurement of absorbed dose to water around an electronic brachytherapy source. Comparison of two dosimetry systems: lithium formate EPR dosimeters and radiochromic EBT2 film, Phys. Med. Biol. 2015, 60 3869–3882. doi: indisponibil

Abstract

Measurement of absorbed dose to water around an electronic brachytherapy source. Comparison of two dosimetry systems: lithium formate EPR dosimeters and radiochromic EBT2 film

Emelie Adolfsson[1,7,8], Shane White[2,7], Guillaume Landry[2,9], Eva Lund[1], Håkan Gustafsson[3], Frank Verhaegen[2,4], Brigitte Reniers[2,5], Åsa Carlsson Tedgren[1,6] and Gudrun Alm Carlsson[1]

[1] Radiation Physics, Department of Medical and Health Sciences, Linköping University, Linköping, Sweden
[2] Department of Radiation Oncology (MAASTRO), GROW—School for Oncology and Developmental Biology, Maastricht University Medical Center, Maastricht 6201 BN, the Netherlands
[3] Department of Clinical Engineering (MTÖ), Radiation Physics, Department of Medicine and Health Sciences, Linköping University, Linköping, Sweden
[4] Medical Physics Unit, Department of Oncology, McGill University, Montréal, Québec H3G 1A4, Canada
[5] Research group NuTeC, CMK, Hasselt University, Agoralaan Gebouw H, B-3590 Diepenebeek, Belgium
[6] Swedish Radiation Safety Authority, Stockholm, Sweden

E-mail: Emelie.adolfsson@regionostergotland.se

Received 2 October 2014, revised 2 January 2015
Accepted for publication 13 January 2015
Published 23 April 2015

Abstract

Interest in high dose rate (HDR) electronic brachytherapy operating at 50 kV is increasing. For quality assurance it is important to identify dosimetry systems that can measure the absorbed doses in absolute terms which is difficult in this energy region. In this work a comparison is made between two dosimetry systems, EPR lithium formate dosimeters and radiochromic EBT2 film.

Both types of dosimeters were irradiated simultaneously in a PMMA phantom using the Axxent EBS. Absorbed dose to water was determined at distances of 10 mm, 30 mm and 50 mm from the EBS. Results were traceable to different primary standards as regards to absorbed dose to water (EPR) and air kerma (EBT2). Monte Carlo simulations were used in absolute terms as a third estimate of absorbed dose to water.

Agreement within the estimated expanded ($k = 2$) uncertainties (5% (EPR), 7% (EBT2)) was found between the results at 30 mm and 50 mm from the x-ray source. The same result was obtained in 4 repetitions of irradiation, indicating high precision in the measurements with both systems. At all distances, agreement between EPR and Monte Carlo simulations was shown as was also the case for the film measurements at 30mm and 50mm. At 10mm the geometry for the film measurements caused too large uncertainty in measured values depending on the exact position (within sub-mm distances) of the EBS and the 10 mm film results were exculded from comparison.

This work has demonstrated good performance of the lithium formate EPR dosimetry system in accordance with earlier experiments at higher photon energies (^{192}Ir HDR brachytherapy). It was also highlighted that there might be issues regarding the energy dependence and intrinsic efficiency of the EBT2 film that need to be considered for measurements using low energy sources.

Keywords: electronic brachytherapy, EPR, lithium formate, radiochromic film, intrinsic efficiency

(Some figures may appear in colour only in the online journal)

Concluzii

5. Conclusions

This work is a contribution to developing reliable experimental methods suitable for dosimetry around low energy brachytherapy sources, in particular high dose rate EBS. The EPR dosimeters were found to yield results in agreement with Monte Carlo simulations at three distances (10, 30 and 50 mm) from the source in the phantom. The EBT2 films agreed with Monte Carlo and EPR at 30 mm and 50 mm. At 10 mm, the uncertainty in the exact positioning of the EBS was too large to get a reliable estimate using EBT2 films. This work has shown the complexity of measurements around this type of source and the importance of detailed knowledge of the properties of the dosimetry system used. It was also shown that lithium formate EPR dosimetry is a good candidate for the purpose and it was deduced that there might be issues regarding energy dependence and intrinsic efficiency of the EBT2 film that need to be considered in future measurements.

Articol 5

Ingerid Skjei Knudtsen, Jørund Graadal Svestad, Erlend Peter Skaug Sande, Bernt Louni Rekstad, Jan Rødal, Wouter van Elmpt, Michel Öllers, Eli Olaug Hole and Eirik Malinen, Validation of dose painting of lung tumours using alanine/EPR dosimetry, Phys. Med. Biol., 2016, 61, 2243–2254. doi: indisponibil

Abstract

Validation of dose painting of lung tumours using alanine/EPR dosimetry

Ingerid Skjei Knudtsen[1,2], Jørund Graadal Svestad[1], Erlend Peter Skaug Sande[2], Bernt Louni Rekstad[2], Jan Rødal[2], Wouter van Elmpt[3], Michel Öllers[3], Eli Olaug Hole[1] and Eirik Malinen[1,2]

[1] Department of Physics, University of Oslo, P.O. Box 1048 Blindern, N-0316 Oslo, Norway
[2] Department of Medical Physics, Oslo University Hospital, P.O. Box 4953 Nydalen, N-0424 Oslo, Norway
[3] Department of Radiation Oncology (MAASTRO), GROW—School for Oncology and Developmental Biology, Maastricht University Medical Centre, P.O. Box 3035, 6202 NA Maastricht, The Netherlands

E-mail: i.s.knudtsen@fys.uio.no

Received 9 September 2015, revised 13 January 2016
Accepted for publication 29 January 2016
Published 25 February 2016

Abstract

Biologic image guided radiotherapy (RT) with escalated doses to tumour sub volumes challenges today's RT dose planning and delivery systems. In this phantom study, we verify the capability of a clinical dose planning and delivery system to deliver an 18F-FDG-PET based dose painted treatment plan to a lung tumour. Furthermore, we estimate the uncertainties of the dose painted treatment compared to conventional RT plans. An anthropomorphic thorax phantom of polystyrene and polyurethane was constructed based on CT images of a lung cancer patient. 101 EPR/alanine dosimeters were placed in separate cavities within the phantom. IMRT and VMAT plans were generated in Eclipse (version 10.0, Analytical Anisotropic Algorithm version 10.2.28, Varian Medical Systems, Inc.) for 6 and 15 MV photons, based on 18F-FDG-PET/CT images of the patient. A boost dose of 3.8 Gy/fraction was given to the 18F-FDG-avid region (biological planning volume; BTV), whereas 3.1 Gy/fraction was planned to the planning target volume (PTV, excluding the BTV). For the homogenous plans, 3.2 Gy/fraction was given to the PTV. Irradiation of the phantom was carried out at a Varian Trilogy linear accelerator (Varian Medical Systems, Inc.). Uncertainties involved in treatment planning and delivery were estimated from portal dosimetry gamma evalutation. Measured and calculated doses were compared by Bland–Altmann analysis. For all treatment plans, all dose-volume objectives could be achieved in the treatment planning system. The mean absolute differences between calculated and measured doses were small (<0.1 Gy) for BTV, PTV-BTV, lung and soft tissue. The estimated uncertainty of the planned doses was less than 3% for all plans, whereas the estimated uncertainty in the measured doses was less 2.3%. Our results show that planning and delivery of dose escalated lung cancer treatment on a clinical dose planning and delivery system has high dosimetric accuracy. The uncertainties associated with the dose escalated treatment plans are comparable to the conventional plans.

Keywords: radiotherapy, lung cancer, phantom, IMRT, VMAT, PET, functional imaging

Online supplementary data available from stacks.iop.org/PMB/61/2243/mmedia

(Some figures may appear in colour only in the online journal)

Concluzii

5. Conclusion

We have validated the feasibility of a contour based dose painting approach for an advanced stage lung tumour. The dose distribution within the phantom corresponds well with the calculated dose distribution of the TPS for both DP and homogenous IMRT treatment. The difference between calculated and measured dose are similar regardless of treatment strategy and photon beam energy. This is supported by the uncertainty and Bland Altman analyses, which show no systematic differences between the plans with exception of the geometrical uncertainty. In a clinical setting, strategies to handle tumour motion during imaging and treatment must be employed. Nevertheless, ours results indicate that the dosimetric challenges of the employed dose painting strategy are not related to the dose calculation and delivery of the treatment system.

Articol 6

M.C. D'Ocaa, M. Marralea, L. Abbene, A. Bartolottaa, G. Collura, F. d'Erricod, F. Principato, Alanine films for EPR dosimetry of low-energy (1–30 keV) X-ray photons, Nuclear. Inst. and Methods in Physics Research B, 2019, 459, 1-6. doi: https://doi.org/10.1016/j.nimb.2019.08.011

Abstract

Alanine films for EPR dosimetry of low-energy (1–30 keV) X-ray photons

M.C. D'Oca[a,b], M. Marrale[a,b,c,*], L. Abbene[a], A. Bartolotta[a,b], G. Collura[a,b], F. d'Errico[d,e], F. Principato[a]

[a] Department of Physics and Chemistry, University of Palermo, Viale delle Scienze, Edificio 18, I-90128 Palermo, Italy
[b] Istituto Nazionale di Fisica Nucleare (INFN), Via Santa Sofia, 64, I-95123 Catania, Italy
[c] ATEN Center, University of Palermo Viale delle Scienze, Edificio 18, I-90128 Palermo, Italy
[d] School of Engineering, University of Pisa, Largo Lazzarino 1, I-56126 Pisa, Italy
[e] School of Medicine, Yale University, 333 Cedar St, New Haven CT 06520, United States

ARTICLE INFO

Keywords:
Electron paramagnetic resonance
Low energy photons
Alanine

ABSTRACT

L-α-alanine has aroused considerable interest for use in radiation EPR dosimetry and has been formally accepted as a secondary standard for high-dose (kGy) and transfer dosimetry of high-energy photons and electrons. In this work, we extended the investigation of the energy response of alanine EPR films in the low energy range for X-photons (1–30 keV). Electron Paramagnetic Resonance (EPR) measurements were performed on Kodak BioMax alanine films exposed to low-energy X-rays from a Cu-, W- and Mo-targets tube operating at voltages up to 30 kV. Films were chosen because of the low penetration of the soft X-rays used. The response of alanine to low-energy X-rays was characterized experimentally and the relative response (with respect to high energy photons) was found to be between 0.8 and 0.9 for Cu- and W-tube X-rays, and 1.0 for Mo-tube X-rays. The attenuation profiles were investigated and it was found that 1 mm of film material reduces the intensity of the X-ray-beam by about 70%, 50% and 40% for Cu-, W- and Mo-tube X-rays, respectively. Monte Carlo simulations were performed to model the energy release as well as the depth dose profiles for the various radiation beams used. These data are considered relevant for dosimetric applications in low energy beams such the high-gradient treatment fields used in monoenergetic microbeam radiation therapy (MRT) with synchrotron radiation as well as in brachytherapy with low energy sources, for instance ^{169}Yb.

Concluzii

4. Conclusions

Commercial Kodak BioMax alanine films were exposed to Cu-, W- and Mo-target X-tube photons for doses up to 40 Gy and the relative response (with respect to high energy photons) was found to be between 0.8 and 0.9 for Cu- and W-tube X-rays, and 1.0 Mo-tube X-rays. The attenuation profiles were investigated since these beams are rapidly attenuated: 1 mm of film material reduces their intensity by about 70%, 50% and 40% within 1 mm for Cu-, W- and Mo-tube X-rays, respectively. These results were modelled through Monte Carlo simulations. Therefore, the ~ 100 micron active thickness of the Kodak BioMax alanine films is very useful in the measurement of these low energy X-Rays and they are promising for the dosimetry of low energy synchrotron radiation in the form of microplanar beams for the treatment of brain metastases as well as in brachytherapy with low energy sources.

Articol 7

Catalin Stelian Tuta, Marie Noëlle Amiot, Line Sommier, Razvan Mihail Ioana, Alanine pellets comparison using EPR dosimetry in the frame of quality assurance for a Gamma Knife system in Romania, Radiation Physics and Chemistry, 2020, 170, 108653. doi: https://doi.org/10.1016/j.radphyschem.2019.108653

Abstract

Alanine pellets comparison using EPR dosimetry in the frame of quality assurance for a Gamma Knife system in Romania

Catalin Stelian Tuta[a,*], Marie Noëlle Amiot[b], Line Sommier[b], Razvan Mihail Ioan[a]

[a] Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH), 30 Reactorului Street, Magurele, RO-077125, Romania
[b] CEA, LIST, Laboratoire National Henri Becquerel (LNE-LNHB), CEA-Saclay, 91191, Gif-Sur-Yvette Cedex, France

ARTICLE INFO

Keywords:
Alanine
Electron paramagnetic resonance (EPR) spectrometry
Stereotactic radiosurgery
Dosimetry
Quality assurance

ABSTRACT

In the last decade, the use of alanine/Electronic Paramagnetic Resonance (EPR) system was extended to radiotherapy doses. In stereotactic radiosurgery, doses up to 70 Gy are delivered to the brain tumor preserving healthy tissues. This type of treatment is delivered using dedicated equipment, like Cyberknife or Gamma Knife. Alanine dosimeters are characterized by their small size (5 mm diameter) and by similarity with tissue. They are well adapted for this wide dose range for which the dosimeter response is linear, independent of dose rate and energy for the range around few MeV. Therefore Alanine/EPR system is a suitable method for accurate and stable dose measurements as passive dosimeters for narrow treatment beams, which makes it an excellent candidate for end to end testing of radiosurgery treatments using Gamma Knife. The present work describes the development of the alanine/EPR method at Horia Hulubei National Institute for Physics and Nuclear Engeneering (IFIN-HH) in Romania including the optimization of system parameters for the radiosurgery dose range in the frame of an IFIN-HH and the French national metrology institute Laboratoire National Henri Becquerel federated by the Laboratoire National de métrologie et d'Essais (LNE-LNHB) collaboration. Romanian alanine dose measurements capability is presented regarding a comparison of calibration curves between both National Laboratories using Bruker and Synergy Health alanine pellets.

Concluzii

5. Conclusions

The slopes of the calibration curves obtained for the Bruker and Synergy Health alanine pellets are in an excellent agreement within their uncertainty at LNE-LNHB as well as at IFIN-HH. These results confirm the equivalence between both types of alanine pellets when used for absorbed dose to water measurements. The results presented in this paper validate the alanine/EPR system and the protocols established at IFIN-HH and also show that alanine/EPR dosimetry system is a very good candidate for being used as a transfer dosimeter for Gamma Knife medical procedures.

Articol 8

P. Ramachandran, C. Noble, C. Jones, V. Seshadri, M. Foote, Electron Paramagnetic Resonance Spectroscopy for Gamma Knife Dosimetry, Journal of Physics: Conference Series, 2020, 1662, 012026, doi: https://doi.org/10.1088/1742-6596/1662/1/012026

Abstract

Electron Paramagnetic Resonance Spectroscopy for Gamma Knife Dosimetry

P Ramachandran, C Noble, C Jones, V Seshadri, M Foote
Department of Radiation Oncology, Princess Alexandra Hospital, Woolloongabba, Queensland, Australia 4102

E-mail: prabhakar.ramachandran@health.qld.gov.au

Abstract. Alanine chips exposed to high doses of radiation produces long lived free radicals that could be easily measured with electron paramagnetic resonance (EPR) spectrometers. In this study, the feasibility of using alanine dosimeters for performing rapid quality assurance of Leksell Gamma Knife (LGK) treatment plans was demonstrated. A 3D printed grid was placed inside the LGK spherical solid water phantom (SWP) for measurement of doses at isocentre and off-axis points. The EPR spectroscopy was performed on a Magnettech MS-5000 EPR/ESR spectrometer. A set of dose calibration curves were established prior to the use of alanine chips for LGK dosimetry. Absolute dose, transit dose and dose/timer linearity were performed with the alanine chips positioned at the centre of the LGK solid water phantom (SWP). Five patients of different sites were selected, and patient specific quality assurance (PSQA) was performed in the LGK SWP. The absolute dose measured with the EPR alanine dosimeter agreed well within 2% of the ion chamber results and PSQA results were within 2.1%. Alanine-based EPR dosimetry offers rapid dose measurement with high accuracy and can also be used as a dosimeter for Gamma Knife PSQA.

Concluzii

4. Conclusions

The absolute dose measured with the EPR alanine dosimeter agreed well within 2% of the ion chamber results. Alanine-based EPR dosimetry shows promising and comparable results in Gamma Knife dosimetry and can be used as a dosimeter for patient specific quality assurance suited well for Gamma Knife plans (8 Gy – 180 Gy).

Articol 9

Sebastian Höfel, Michael Stehle, Felix Zwicker, Michael K Fix and Malte Drescher, A practical EPR dosimetry system for routine use in radiotherapy: uncertainty analysis of lithium formate dosimeters at the therapeutic dose level, Phys. Med. Biol., 2021, 66, 045005. doi: indisponibil

Abstract

A practical EPR dosimetry system for routine use in radiotherapy: uncertainty analysis of lithium formate dosimeters at the therapeutic dose level

Sebastian Höfel[1,2], Michael Stehle[1], Felix Zwicker[2], Michael K Fix[3] and Malte Drescher[1]

[1] Department of Chemistry and Konstanz Research School Chemical Biology, University of Konstanz, Germany
[2] Klinik und Praxis für Strahlentherapie am Klinikum Konstanz, Konstanz, Germany
[3] Division of Medical Radiation Physics and Department of Radiation Oncology, Inselspital, Bern University Hospital and University of Bern, Switzerland

E-mail: malte.drescher@uni-konstanz.de

Keywords: EPR dosimetry, alanine, lithium formate, radiotherapy, uncertainty

Abstract

In electron paramagnetic resonance (EPR) dosimetry, solid dosimeter materials such as alanine (AL) or, more recently, lithium formate monohydrate (LFM) are typically used. These materials offer high potential for applications in radiotherapy based on their favorable dosimetric properties. Nevertheless, EPR dosimetry is not widespread in the clinics. This work presents an uncertainty analysis of EPR dosimetry in the dose range from 1 to 70 Gy using a compact spectrometer and applying a practical procedure being suitable for routine use in radiotherapy. The performances of self-pressed LFM pellets and commercial AL pellets are compared side by side.

All pellets had a diameter of 4 mm and a height of 2 mm (AL) or 4 mm (LFM). The mean pellet mass was 35.81 mg and 73.81 mg for AL and LFM, respectively. Before irradiation, the pellets were stored for at least 8 weeks at 34 ± 2% relative humidity. For irradiation, the pellets were put inside an airtight capsule. In total, 25 pellets per material were examined. The pellets were irradiated at a temperature of 25 ± 2.5 (2σ) °C to doses of either 1, 5, 20, 50 or 70 Gy (five pellets per dose value and material) by a clinical 6 MV photon beam. Measurement uncertainties were obtained from five independent readouts per pellet within five weeks following irradiation using a benchtop EPR spectrometer. The measurement time of a single readout was restricted to 10 min per pellet. Dose values were derived from EPR signal amplitudes using a specifically developed spectral fitting procedure. Signal fading characteristics were analyzed and taken into account during evaluation.

The relative dose uncertainties (1σ) for a single readout at doses ≥ 5 Gy are below 2.8% (AL) and 1.1% (LFM) but increase to 12.3% (AL) and 2.6% (LFM) at 1 Gy. By averaging five independent readouts, the uncertainties at 1 Gy decrease to 2.6% (AL) and 0.8% (LFM).

In terms of dose uncertainty, the LFM pellets are superior to the commercial AL pellets owing to their narrower EPR spectrum and approximately doubled mass resulting in higher EPR signal intensities. In case of the LFM pellets, the EPR dosimetry system shows a high level of precision (< 3%) down to 1 Gy being preferable for applications in radiotherapy. The uncertainties can be further decreased by averaging multiple dose values from independent readouts.

Concluzii

5. Conclusion

Precise dose measurements at the therapeutic dose level (1–70 Gy) are feasible on a EPR benchtop spectrometer by implementing a practicable EPR dosimetry procedure. In terms of uncertainty at low doses (< 20 Gy), the self-made LFM pellets are superior to the AL pellets received from the manufacturer owing to their narrower EPR spectrum and approximately doubled mass resulting in higher EPR signal intensities. However, careful calibration and the knowledge of fading characteristics are prerequisites when analyzing LFM signals. By following the elaborated dosimetry procedure, relative dose uncertainties of less than 3% at 1 Gy can be achieved for LFM based upon a single readout (10 min) and daily recording of the manganese reference signal for 1 h. The uncertainties can be further decreased by averaging multiple dose values from independent readouts. In principle, the presented dosimetry system is considered suitable for future on-site applications in EBRT. However, overall uncertainties may increase due to less-controlled circumstances in clinical routine. For example, irradiation temperatures may be more variable when dosimeters are applied *in-vivo*.

Articol 10

Sebastian Höfel, Michael K. Fix, Malte Drescher, Felix Zwicker, Suitability of superficial electron paramagnetic resonancedosimetry for in vivo measurement and verification ofcumulative total doses during IMRT: A proof of principle, Z Med Phys., 31 (2021) 365–377, https://doi.org/10.1016/j.zemedi.2021.03.006

Abstract

Abstract

Purpose: *The present study investigates superficial in vivo dosimetry (IVD) by means of a previously proposed electron paramagnetic resonance (EPR) dosimetry system aiming at measuring and verifying total doses delivered by complex radiotherapy treatments. In view of novel regulatory requirements in Germany, differences between measured and planned total doses to the EPR dosimeters are analyzed and compared to reporting thresholds for significant occurrences.*

Methods: *EPR dosimeters, each consisting of one lithium formate monohydrate (LFM) and one polycrystalline L-alanine (ALA) pellet, were attached to the surface of an anthropomorphic head phantom. Three head and neck treatments with total target doses ranging from 30 to 64 Gy were fully delivered to the phantom by helical tomotherapy. During each treatment, eight EPR dosimeters were placed at distinct spots: (i) within or next to the planning target volume (PTV), (ii) near to organs at risk including the parotid glands and the eye lenses, (iii) at the thyroid lying out-of-field. EPR read out was always performed after all fractions were delivered. EPR results were compared to thermoluminescence dosimeter (TLD) measurements and to the planned total doses derived from the treatment planning system (TPS). Planned total doses to the EPR dosimeters ranged from about 2 to 64 Gy.*

Results: *By taking uncertainties into account, the measured and planned doses were in good agreement. Exceptions occurred mainly at the thyroid (out-of-field) and lenses (extreme sparing). The maximum total dose difference between EPR results and corresponding planned doses was 1.3 Gy occurring at the lenses. Remarkably, each LFM and ALA pellet placed within or next to the PTV provided dose values that were within ±4% of the planned dose. Dose deviations from planned dose values were comparable for EPR and TLD measurements.*

Conclusion: *The results of this proof of principle study suggest that superficial EPR-IVD is applicable in a wide dose range and in various irradiation conditions – being a valuable tool for monitoring cumulative total doses delivered by complex IMRT treatments. EPR-IVD in combination with helical tomotherapy is suitable to reliably detect local dose deviations at superficial dosimeter spots in the order of current national reporting thresholds for significant occurrences (i.e. 10%/4 Gy).*

Keywords: In vivo, EPR dosimetry, Lithium formate, Alanine, Intensity modulated radiotherapy, Tomotherapy

Concluzii

5 Conclusion

The present study shows that superficial in vivo EPR dosimetry is suitable for measuring and verification of total doses delivered during complex IMRT treatments for all cases considered.

EPR-IVD in this work was performed with two different dosimeter materials: Self-pressed LFM and commercial ALA pellets. Due to their higher robustness regarding contouring errors and misplacements as well as higher levels of precision at lower doses, the LFM pellets used in this work are preferable for IVD compared to commercial ALA pellets.

Relevant differences between measured and planned total doses in the order of current reporting thresholds for significant occurrences (10%/4 Gy) can be reliably detected by superficial EPR dosimetry and, thus, superficial EPR-IVD may serve as an additional safeguard during the delivery of complex IMRT treatments in the future.

Articol 11

Sebastian Höfel , Matteo Gandalini, Michael K. Fix, Malte Drescher and Felix Zwicker, Prospective superficial EPR in-vivo dosimetry study during hypofractionated radiotherapy of breast cancer patients treated with helical tomotherapy, Radiat. Oncol., 2021, 16, 209. doi: https://doi.org/10.1186/s13014-021-01938-8

Abstract

Abstract

Background: In-vivo dosimetry (IVD) is a patient specific measure of quality control and safety during radiotherapy. With regard to current reporting thresholds for significant occurrences in radiotherapy defined by German regulatory authorities, the present study examines the clinical feasibility of superficial electron paramagnetic resonance (EPR) IVD of cumulative total doses applied to breast cancer patients treated with helical intensity-modulated radiotherapy (tomotherapy).

Methods: In total, 10 female patients with left- or right-sided breast cancer were enrolled in this prospective IVD study. Each patient received a hypofractionated whole breast irradiation. A total median dose of 42.4 Gy in 16 fractions (5 fractions per week) was prescribed to the planning target volume. The treatments were completely delivered using helical tomotherapy and daily image guidance via megavoltage CT (MVCT). For each patient, three EPR dosimeters were prepared and placed at distinct locations on the patient's skin during the delivery of all fractions. Two dosimeters were placed next to the ipsilateral and contralateral mammilla and one dosimeter was placed ventrally to the thyroid (out-of-primary-beam). The total doses delivered to the dosimeters were readout after all fractions had been administered. The measured total dose values were compared to the planned dose values derived from the treatment planning system (TPS). Daily positional variations (displacement vectors) of the ipsilateral mammilla and of the respective dosimeter were analyzed with respect to the planned positions using the daily registered MVCT image.

Results: Averaged over all patients, the mean absolute dose differences between measured and planned total dose values (± standard deviation (SD)) were: 0.49 ± 0.85 Gy for the ipsilateral dosimeter, 0.17 ± 0.49 Gy for the contralateral dosimeter and -0.12 ± 0.30 Gy for the thyroid dosimeter. The mean lengths of the ipsilateral displacement vectors (± SD) averaged over all patients and fractions were: 10 ± 7 mm for the dosimeter and 8 ± 4 mm for the mammilla.

Conclusion: Superficial EPR IVD is suitable as additional safeguard for dose delivery during helical tomotherapy of breast cancer. Despite positional uncertainties in clinical routine, the observed dose deviations at the ipsilateral breast were on average small compared to national reporting thresholds for total dose deviations (i.e. 10%/4 Gy). EPR IVD may allow for the detection of critical dose errors during whole breast irradiations.

Concluzii

Conclusion

Despite remaining positional uncertainties during image-guided helical tomotherapy of breast cancer, the dose differences between planned and measured cumulative total doses obtained via superficial EPR IVD as well as combined uncertainties of the dose differences were small for the ipsilateral dosimeter compared to current reporting thresholds in radiotherapy. Thus, EPR IVD is suitable and clinically feasible to assist in detecting, preventing and investigating severe dose misadministration to the treated breast according to current reporting criteria. Dose delivery to the contralateral breast and to the thyroid lying out-of-field could be monitored down to approximately 1 Gy cumulative dose. Superficial EPR IVD is to be seen as an additional safeguard for monitoring cumulative total doses to radiotherapy patients. In future clinical routine, superficial EPR IVD could assist in recognizing treatment errors and may support further investigations whether the criteria for reporting are met.

Articol 12

C. De Angelis, S. Onori, E Petetti, A. Piermattei and L. Azario, Alanine/EPR dosimetry in brachytherapy, Phys. Med. Biol., 1999, 44, 1181–1191. doi: indisponibil

Abstract

Alanine/EPR dosimetry in brachytherapy

C De Angelis†‡, S Onori†, E Petetti†, A Piermattei§ and L Azario§

† Physics Laboratory, Istituto Superiore di Sanità, Viale Regina Elena 299, 00161 Rome, Italy
§ Physics Institute, Università Cattolica S Cuore, Largo Francesco Vito 1, 00168 Rome, Italy

Received 4 December 1998

Abstract. The paper reports the experimental procedure adopted to determine the absorbed dose rate in water per reference air kerma rate, $D_{K_r}(d,\theta)$, along the transverse bisector axis of a ^{137}Cs brachytherapy source. The dose rate measurements have been carried out at difference distances, d, from the source using alanine dosemeters in a water phantom. The reference air kerma rate, $\dot{K}_r$, was determined adopting a 'direct procedure' that uses a spherical ionization chamber in air. The dose rate constant of the source examined was $D_{K_r}(1,\pi/2) = 0.99 \pm 0.03$ cGy h^{-1} (μGy h^{-1})$^{-1}$. The values of the radial dose function along the transverse axis, $g(d)$, determined with an uncertainty of 3.4% (1σ), were found to be in good agreement with the results reported in the literature.

The uncertainty in dose rate value has been estimated as 2.8% (1σ) for distances from the source up to 7 cm. $\dot{K}_r$ has been determined with 1.2% (1σ) uncertainty. So $D_{K_r}(d,\pi/2)$ values were determined with 3% (1σ) uncertainty.

Concluzii

In conclusion, the use of alanine/EPR dosimetry and of a properly designed water phantom made it possible to calibrate a brachytherapy ^{137}Cs source with an uncertainty comparable to or even better than that achievable using more conventional dosimetry systems. The same experimental approach can be used for high-activity ^{192}Ir sources. Indeed, as shown in table 1, the relative calibration factor of alanine dosemeters varies by about 1% for 1 to 7 cm distances from an ^{192}Ir source. The same table shows a 6% variation for TLD-100 in the same distance range. Unfortunately, alanine/EPR dosimetry requires expensive EPR spectrometers, trained personnel, long irradiation times and detectors not easily available on the market. So a possible working scheme could be one in which a reference laboratory (at national or international level) will use alanine as a transfer dosemeter. The hospital centre that uses a specific type of source should measure the strength of the source in terms of $\dot{K}_r$ and irradiate alanine dosemeters in a proper water phantom, both provided by the reference laboratory. Then, the reference laboratory will carry out the EPR readout. It should be remembered that alanine/EPR dosimetry has negligible fading (<0.5% per year at RT) (Regulla and Deffner 1982, Onori *et al* 1990) which is an important requisite in the proposed working scheme.

The $D_{K_r}(d,\pi/2)$ values so obtained for that type of source can be used both in centres that use the same source and when a new source of the same type is introduced in a centre due to radioactive decay. Moreover, verification of treatment planning dose computation can be performed with alanine dosimetry when complex source configurations are used, for example in the case of treatments obtained using a source in motion into the applicator as well as treatments with multisource systems.

Articol 13

G. G. Zeng, M. R. McEwen, D. W. O. Rogers and N. V. Klassen, An experimental and Monte Carlo investigation of the energy dependence of alanine/EPR dosimetry: II. Clinical electron beams, Phys. Med. Biol., 2005, 50 1119–1129. doi: https://doi.org/10.1088/0031-9155/50/6/006

Abstract

An experimental and Monte Carlo investigation of the energy dependence of alanine/EPR dosimetry: II. Clinical electron beams

G G Zeng[1], M R McEwen, D W O Rogers[2] and N V Klassen

Ionizing Radiation Standards, National Research Council of Canada, Ottawa K1A 0R6, Canada

E-mail: Grace.Zeng@rmp.uhn.on.ca

Received 26 October 2004
Published 23 February 2005
Online at stacks.iop.org/PMB/50/1119

Abstract

The energy dependence of alanine/EPR dosimetry for 8, 12, 18 and 22 MeV clinical electron beams was investigated by experiment and by Monte Carlo simulations. Alanine pellets in a waterproof holder were irradiated in a water phantom using an Elekta Precise linear accelerator. The dose rates at the reference point were determined following the TG-51 protocol using an NACP-02 parallel-plate chamber calibrated in a ^{60}Co beam. The EPR spectra of irradiated pellets were measured using a Bruker EMX 081 EPR spectrometer. Experimentally, we found no significant change in alanine/EPR response to absorbed dose-to-water over the energy range 8–22 MeV at an uncertainty level of 0.6%. However, the response for high-energy electrons is about 1.3 (±1.1)% lower than for ^{60}Co. The EGSnrc Monte Carlo system was used to calculate the ratio of absorbed dose-to-alanine to absorbed dose-to-water and it was shown that there is 1.3 (±0.2)% reduction in this ratio from the ^{60}Co beam to the electron beams, which confirms the experimental results. Alanine/EPR response per unit absorbed dose-to-alanine was also investigated and it is the same for high-energy electrons and ^{60}Co γ-rays.

Concluzii

6. Conclusions

In this study, we investigated the energy dependence of alanine/EPR dosimetry for clinical electron beams. It was found that alanine/EPR response per unit absorbed dose-to-water at the standard reference depth does not depend on electron beam energy, but it is about 1.3% lower than that for ^{60}Co γ-rays. Furthermore, within the experimental and calculation uncertainties, the radiation yield, based on dose-to-alanine, is the same for clinical electron beams as that for ^{60}Co γ-rays.

Note added in proof. Since the acceptance of this manuscript, a report of a similar study, 'An experimental investigation of the electron energy dependence of the EPR alanine dosimetry system' by Bergstrand *et al*, has been published in *Radiation Measurements* **39** (2005) 21–8.

Articol 15

Laura Antonovic, Håkan Gustafsson, Gudrun Alm Carlsson, and Åsa Carlsson Tedgrena, Evaluation of a lithium formate EPR dosimetry system for dose measurements around 192Ir brachytherapy sources, Medical Physics, 2009, 36, 2236-2247. doi: https://doi.org/10.1118/1.3110068

Abstract

Evaluation of a lithium formate EPR dosimetry system for dose measurements around ^{192}Ir brachytherapy sources

Laura Antonovic, Håkan Gustafsson, Gudrun Alm Carlsson, and Åsa Carlsson Tedgren[a)]
Department of Medical and Health Sciences (IMH), Radiation Physics, Faculty of Health Sciences, Linköping University, SE-581 85 Linköping, Sweden

(Received 27 September 2008; revised 9 March 2009; accepted for publication 10 March 2009; published 18 May 2009)

A dosimetry system using lithium formate monohydrate ($HCO_2Li \cdot H_2O$) as detector material and electron paramagnetic resonance (EPR) spectroscopy for readout has been used to measure absorbed dose distributions around clinical ^{192}Ir sources. Cylindrical tablets with diameter of 4.5 mm, height of 4.8 mm, and density of 1.26 g/cm^3 were manufactured. Homogeneity test and calibration of the dosimeters were performed in a 6 MV photon beam. ^{192}Ir irradiations were performed in a PMMA phantom using two different source models, the GammaMed Plus HDR and the microSelectron PDR-v1 model. Measured absorbed doses to water in the PMMA phantom were converted to the corresponding absorbed doses to water in water phantoms of dimensions used by the treatment planning systems (TPSs) using correction factors explicitly derived for this experiment. Experimentally determined absorbed doses agreed with the absorbed doses to water calculated by the TPS to within ±2.9%. Relative standard uncertainties in the experimentally determined absorbed doses were estimated to be within the range of 1.7%–1.3% depending on the radial distance from the source, the type of source (HDR or PDR), and the particular absorbed doses used. This work shows that a lithium formate dosimetry system is well suited for measurements of absorbed dose to water around clinical HDR and PDR ^{192}Ir sources. Being less energy dependent than the commonly used thermoluminescent lithium fluoride (LiF) dosimeters, lithium formate monohydrate dosimeters are well suited to measure absorbed doses in situations where the energy dependence cannot easily be accounted for such as in multiple-source irradiations to verify treatment plans. Their wide dynamic range and linear dose response over the dose interval of 0.2–1000 Gy make them suitable for measurements on sources of the strengths used in clinical applications. The dosimeter size needs, however, to be reduced for application to single-source dosimetry. © *2009 American Association of Physicists in Medicine*. [DOI: 10.1118/1.3110068]

Key words: experimental ^{192}Ir dosimetry, electron paramagnetic resonance detector

Concluzii

VI. CONCLUSIONS

The lithium formate EPR dosimetry system investigated has shown to yield accurate results when used to determine absorbed doses around ^{192}Ir brachytherapy sources. Its low-energy dependence relative to water makes it more suitable for dose verification than LiF TL dosimetry systems in clinically relevant situations (multisource implants and stepping-source irradiations where the photon energy spectrum in the general situation is unknown and hence cannot be corrected for). The wide dose-response linearity of the system is an advantage since dose distributions around PDR and HDR ^{192}Ir sources can be measured for sources of clinical strength and dosimeters can be irradiated at different distances from the source(s) within one irradiation. Before the lithium formate EPR dosimetry system can be used for experimental verification of absorbed dose distributions around single sources or in other situations where dose gradients are steeper than in the present work, methods of producing and measuring with smaller dosimeters must be developed to keep the volume averaging correction reasonably low in situations with steep dose gradients such as those close (<3 cm) to a single source.

Articol 16

Carmen S Guzman Calcina, Adelaide de Almeida, Jose R Oliveira Rocha, Felipe Chen Abrego and Oswaldo Baffa, Ir-192 HDR transit dose and radial dose function determination using alanine/EPR dosimetry, Phys. Med. Biol. 50 (2005) 1109–1117 doi: https://doi.org/10.1088/0031-9155/50/6/005

Abstract

Abstract

Source positioning close to the tumour in high dose rate (HDR) brachytherapy is not instantaneous. An increment of dose will be delivered during the movement of the source in the trajectory to its static position. This increment is the transit dose, often not taken into account in brachytherapeutic treatment planning. The transit dose depends on the prescribed dose, number of treatment fractions, velocity and activity of the source. Combining all these factors, the transit dose can be 5% higher than the prescribed absorbed dose value (Sang-Hyun and Muller-Runkel 1994 *Phys. Med. Biol.* **39** 1181–8, Nath *et al* 1995 *Med. Phys.* **22** 209–34). However, it cannot exceed this percentage (Nath *et al* 1995). In this work, we use the alanine-EPR (electron paramagnetic resonance) dosimetric system using analysis of the first derivative of the signal. The transit dose was evaluated for an HDR system and is consistent with that already presented for TLD dosimeters (Bastin *et al* 1993 *Int. J. Radiat. Oncol. Biol. Phys.* **26** 695–702). Also using the same dosimetric system, the radial dose function, used to evaluate the geometric dose degradation around the source, was determined and its behaviour agrees better with those obtained by Monte Carlo simulations (Nath *et al* 1995, Williamson and Nath 1991 *Med. Phys.* **18** 434–48, Ballester *et al* 1997 *Med. Phys.* **24** 1221–8, Ballester *et al* 2001 *Phys. Med. Biol.* **46** N79–90) than with TLD measurements (Nath *et al* 1990 *Med. Phys.* **17** 1032–40).

Concluzii

4. Conclusions

The static dose D_{sx} may be planned in the conventional way by the medical physicist, and the transit dose D_{tx} must be considered and, when significant, added to the static dose. The transit dose values, obtained for the first time using a first harmonic alanine-EPR dosimeter, are close to those reported in the literature using TLD.

The radial dose function, obtained from alanine EPR measurements, agrees with Monte Carlo simulations. The agreement with TLD values is satisfactory only for distances less than 5 cm.

We conclude that the alanine-EPR dosimeter can be useful for HDR brachytherapeutic dosimetry. Smaller alanine dosimeters could be used for higher spatial resolution.

Articol 17

Abbas Nasreddinea,, Florent Kuntza, Ziad El Bitar, Absorbed dose to water determination for kilo-voltage X-rays using alanine/EPR dosimetry systems, Radiation Physics and Chemistry 180, 2021, 108938, doi: https://doi.org/10.1016/j.radphyschem.2020.108938

Abstract

Radiation Physics and Chemistry 180 (2021) 108938

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

Absorbed dose to water determination for kilo-voltage X-rays using alanine/EPR dosimetry systems

Abbas Nasreddine[a,b,*], Florent Kuntz[a], Ziad El Bitar[b,c]

[a] Aerial, 250 Rue Laurent Fries, 67400, Illkirch Graffenstaden, France
[b] Institut Pluridisciplinaire Hubert Curien, 23 Rue de Loess, 67000, Strasbourg, France
[c] Laboratory of Physics and Modeling, EDST, Lebanese University, 1300, Tripoli, Lebanon

ARTICLE INFO

Keywords:
Absorbed dose to water
Alanine/EPR
kV X-rays
Monte Carlo simulations

ABSTRACT

Alanine's relative response to kilo-voltage X-rays, compared to ^{60}Co reference quality beam, was studied in this work, in order to determine correction factors to be applied to alanine's response when irradiated with low to medium energy X-rays (up to 300 keV).

The relative response to kilo-voltage X-rays of Aerial's alanine dosimeters was determined by three distinct methods: experimental measurements using alanine dosimeters and a calibrated PTW Farmer 30013 ion chamber, Monte Carlo simulations using MCNPX code and finally, analytical calculations based on weighting of X-ray spectra by NIST's published mass energy absorption coefficients. Two sets of X-ray beam qualities, covering high voltages ranging from 50 kV up to 280 kV, were used to study the energy dependence of the alanine dosimeter's response. Obtained results were consistent within 2.1% (average standard deviation at k = 1).

Concluzii

5. Conclusion

Alanine dosimeter's relative response to kilo-voltage X-rays, compared to ^{60}Co reference beam quality, was studied in this work. The relative response was determined by three different methods. Studied beam qualities covered the range of 50–280 kV (aluminum HVL: from 1.5 to 19.6 mm – aluminum effective energy: from 25 to 168 keV).

Experimental measurements were performed at Aerial and NPL to study alanine's relative response per dose to water unit for different X-ray beam qualities. Obtained results were in a good agreement with already published data (Anton and Büermann, 2015) (Waldeland and Malinen, 2011) (Waldeland et al., 2010), yet a slight difference is noticed due to the difference in the dosimeter's composition and irradiation geometry.

Monte Carlo simulations and analytical calculations determined the ratio of the absorbed dose in alanine with respect to water. Results were in a good agreement with ones obtained by Waldeland and Anton, as well as with results obtained in this study by experimental measurements (average standard deviation of 2.1%, at $k = 1$).

Measuring absorbed dose to water with alanine dosimeters irradiated with kilo-voltage X-rays, using a ^{60}Co calibrated EPR system, requires application of correction factors to the dosimeter's measured EPR response. The three studied methods of determination of alanine's relative response to kilo-voltage X-rays ensure a good estimation of such correction factors.

Analytical calculations seem to be a simple, rapid and trustworthy method to determine correction factors to be applied to alanine's response measured by EPR spectrometry. Yet, the energy dependence of the free radical creation yield (G-value [radicals]/100eV) in alanine needs to be studied in order to integrate this phenomenon in both, simulations and calculations.

Articol 18

Junwang Guo, Lei Ma, Xiaoguang Bi, Guofu Dong, Yonggang Li, Jing Ning, Ke Wu, X-band TE101 rectangular aperture cavity for in vivo EPR tooth dosimetry after radiation emergency, Applied Radiation and Isotopes 178 (2021) 109958, https://doi.org/10.1016/j.apradiso.2021.109958

Abstract

X-band TE101 rectangular aperture cavity for in vivo EPR tooth dosimetry after radiation emergency

Junwang Guo [a,b], Lei Ma [a,b], Xiaoguang Bi [a,b], Guofu Dong [a,b], Yonggang Li [a,b], Jing Ning [a,b], Ke Wu [a,b,*]

[a] Beijing Institute of Radiation Medicine, No.27 Tai-Ping Road, Beijing, 100850, China
[b] Beijing Key Laboratory of Radiation Biology No. BZ0325, No.27 Tai-Ping Road, Beijing, 100850, China

ARTICLE INFO

Keywords:
EPR cavity
In vivo
EPR dosimetry
X-band
TE101 mode

ABSTRACT

The TE101 mode rectangle EPR cavity was newly developed to achieve X-band in vivo EPR tooth dosimetry for the rescue of nuclear emergency. An aperture for sample detection was opened on the cavity's surface. Its characteristics were evaluated by measuring DPPH and intact human incisor samples. Remarkable radiation induced signal from EPR spectrum of 1Gy–8Gy irradiated teeth was observed. In vivo measurements of rat was performed to verify its application for in vivo tooth dosimetry.

Concluzii

4. Discussion

The development of this kind of X-band EPR cavity used a detection aperture opened on the cavity wall for in vivo purpose, and took the advantage of TE101 rectangular mode. The electromagnetic field distribution in TE101 mode rectangle cavity offers the way of external detection instead of inside the cavity. Microwave magnetic field loops surround the cavity's surrounding metal walls and its intensity reaches the highest near the middle of the cavity wall, where there exists an aperture for sample inserting. At the same time, the aperture causes little microwave electric field attenuation and surface current cutting. The experiments of intact incisor irradiated by 1 Gy showed that radiation induced signal could be obtained within just short time scan, which strongly suggests the feasibility of in vivo tooth dose measurement by X-band EPR technique.

We have developed TE111 and TM010 mode cavities for in vivo teeth measurements before. Compared with our previous work of TE111 and TM010 mode cavities, this cavity showed better performance in the detection sensitivity. It provided an better solution for X-band in vivo tooth dosimeter. In the future, more works to improve cavity's quality factor Q, coupling, cavity shape and aperture shape should be pursued.

Articol 19

Yasuhiro Nakai, Ichiro Yamaguchi, Hiroshi Hirata, Harold M. Swartz, Ann Barry Flood, Benjamin B. Williams, Wilson Schreiber, Minoru Miyake, Effects of Ultraviolet Rays on L-Band In Vivo EPR Dosimetry Using Tooth Enamel, Applied Magnetic Resonance

(2022) 53:305–318, https://doi.org/10.1007/s00723-021-01340-3

Abstract

Effects of Ultraviolet Rays on L-Band In Vivo EPR Dosimetry Using Tooth Enamel

Yasuhiro Nakai[1] · Ichiro Yamaguchi[2] · Hiroshi Hirata[3] · Harold M. Swartz[4,5,6] · Ann Barry Flood[4,6] · Benjamin B. Williams[4,5] · Wilson Schreiber[6] · Minoru Miyake[1]

Received: 1 January 2021 / Revised: 16 April 2021 / Accepted: 25 April 2021 /
Published online: 10 July 2021

Abstract
L-band electron paramagnetic resonance (EPR) in vivo dosimetry has the potential advantage of being able to accurately and sensitively measure the absorbed dose of ionizing radiation by measurements of teeth in situ. The equipment is transportable to the site where a radiation incident occurred and can be operated without specialized facilities. It, therefore, is very suitable for medical triage of victims in a large-scale radiation incident to quickly determine whether the dose was large enough to require urgent care. The measurements are made on the outer surfaces of the two upper incisor teeth. However, some in vitro studies of extracted teeth using higher frequency EPR have suggested that exposure to ultraviolet rays (UV) from sunlight might confound estimates of the dose of ionizing radiation made with EPR. Because the outer surfaces of incisors are likely to be exposed to UV/sunlight, it, therefore, is essential to determine the potential quantitative impact of UV on L-band EPR dosimetry measurements based on incisors. We, therefore, investigated the quantitative effect of UV on the EPR signal from ionizing irradiation of human teeth using the L-band spectrometer developed for field dosimetry. The UV-generated EPR signal was very small relative to the signals resulting from doses of ionizing radiation that are used for triage. For example, using our estimates of the effects of UV, for a lifetime of 50 years of exposure of these teeth (assuming an average exposure to sunlight of two hours/day), the expected average lifetime effect of UV-induced signal would be equivalent to 0.33 Gy; in contrast, triage criteria for accidental exposure to ionizing irradiation generally start at 2.0 Gy.

Concluzii

5 Summary and Conclusions

Quantitative in vitro studies of EPR signals generated in incisor teeth by well-defined UV- A and UV-B sources indicate that the impact on triage decisions based on a threshold of 2 Gy from UV exposure on the magnitude of the EPR signals is very low (approx. 6–7 mGy/yr) when measured in the L-band in vivo spectrometer that usually is used for measurements in teeth in vivo. These results indicate that the UV radiation in sunlight is very unlikely to be a significant confounder to EPR dosimetry for triage based on in vivo L-band tooth dosimetry measurements in upper incisor teeth.

Articol 20

Christina Beinke, Christian Siebenwirth, Michael Abend, Matthias Port, Contribution of Biological and EPR Dosimetry to the Medical Management Support of Acute Radiation Health Effects, Applied Magnetic Resonance (2022) 53:265–287, doi: https://doi.org/10.1007/s00723-021-01457-5

Abstract

Contribution of Biological and EPR Dosimetry to the Medical Management Support of Acute Radiation Health Effects

Christina Beinke[1] · Christian Siebenwirth[1] · Michael Abend[1] · Matthias Port[1]

Received: 12 February 2021 / Revised: 22 November 2021 / Accepted: 25 November 2021 /
Published online: 20 December 2021

Abstract

In this review, we discuss the value of biological dosimetry and electron paramagnetic resonance (EPR) spectroscopy in the medical management support of acute radiation syndrome (ARS). Medical management of an ionizing radiation scenario requires significant information. For optimal medical aid, this information has to be rapidly (< 3 days) delivered to the health-care provider. Clinical symptoms may initially enable physicians to predict ARS and initiate respective medical treatment. However, in most cases at least further verification through knowledge on radiation exposure details is necessary. This can be assessed by retrospective dosimetry techniques, if it is not directly registered by personal dosimeters. The characteristics and potential of biological dosimetry and electron paramagnetic resonance (EPR) dosimetry using human-derived specimen are presented here. Both methods are discussed in a clinical perspective regarding ARS diagnostics. The presented techniques can be used in parallel to increase screening capacity in the case of mass casualties, as both can detect the critical dose of 2 Gy (whole body single dose), where hospitalization will be considered. Hereby, biological dosimetry based on the analysis of molecular biomarkers, especially gene expression analysis, but also in vivo EPR represent very promising screening tools for rapid triage dosimetry in early-phase diagnostics. Both methods enable high sample throughput and potential for point-of-care diagnosis. In cases of higher exposure or in small-scale radiological incidents, the techniques can be used complementarily to understand important details of the exposure. Hereby, biological dosimetry can be employed to estimate the whole body dose, while EPR dosimetry on nails, bone or teeth can be used to determine partial body doses. A comprehensive assessment will support optimization of further medical treatment. Ultimately, multipath approaches are always recommended. By tapping the full potential of all diagnostic and dosimetric methods, effective treatment of patients can be supported upon exposure to radiation.

Concluzii

4 Conclusion

Until a reliable bioindicator of effect with regard to the risk of developing ARS and for routine use is available, dose information including dose heterogeneity as well as dose distribution is crucial for medical treatment planning. Furthermore, local dose assessment might be indispensable to guide medical treatment in high local irradiation scenarios. Available retrospective dosimetry methods exhibit different suitability for different exposure scenarios and the most informative method or combination of methods with regard to a specific case and its circumstances should be selected for diagnosis. Finally, the application of several complementary methods is strongly recommended for medical treatment and decision-making support, because most scenarios are of a rather complex nature and each case has its own characteristics. Ideally, this is supported by a strong network of laboratories, which share the workload, enable fast dose reporting and provide a high-quality standard by standardization and inter-laboratory comparisons.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00723-021-01457-5.

Articol 21

Agnieszka Marciniak, Bartłomiej Ciesielski, Małgorzata Juniewicz, EPR dosimetry in glass: a review, Radiation and Environmental Biophysics (2022) 61:179–203, https://doi.org/10.1007/s00411-022-00970-w

Abstract

EPR dosimetry in glass: a review

Agnieszka Marciniak[1] · Bartłomiej Ciesielski[1] · Małgorzata Juniewicz[1]

Received: 23 July 2021 / Accepted: 26 February 2022 / Published online: 20 March 2022

Abstract
Electron Paramagnetic Resonance (EPR) spectroscopy enables detection of paramagnetic centers generated in solids by ionising radiation. In the last years, the ubiquity of glass in personal utility items increased significance of fortuities retrospective dosimetry based on EPR in glass parts of mobile phones and watches. Despite of fading of the signals and their susceptibility to light, it enables dosimetry at medical triage level of 1–2 Gy. In this article information relevant for assessment of applicability and planning of the EPR dosimetry is presented—particularly at dose levels typical for radiation accidents. Reported data on fading of the radiation-induced spectral components are presented and compared. Effects of light on background spectra and on the dosimetric signals are also presented. It is concluded that when properly accounting for the fading and for the obscuring effects of light, the EPR dosimetry in glasses from mobile phones and watches can be used in dose assessment after radiation accidents.

Keywords EPR · Dosimetry · Ionizing radiation · ESR · Glass · Dose

Concluzii

Conclusion

Results of the studies discussed in this brief review confirm applicability of EPR signals in glasses for fortuities dosimetry of ionising radiation following unexpected, accidental exposures of humans and their closest environment to doses of a few Gy. In particular, dosimetry based on glasses from ubiquitous utility items kept close to the body, like mobile phones and wrist watches, allows to achieve a sensitivity of detection on the level of 1–2 Gy, which is sufficient for triage of exposed individuals before planning further medical actions. However, there are two crucial requirements to be fulfilled, in order to obtain reliable results of the EPR dosimetry. The first is implementation of a proper correction in analytical procedures accounting for rapid fading of the dosimetric signal during the first 6–10 days after irradiation.

The second is taking into account potential exposures of the irradiated glass to light, particularly to the UV component of sunlight. Depending on the method used for determination of the dosimetric signal (amplitude or numerical decomposition), neglecting the light effects can introduce remarkable over- or underestimation of the reconstructed doses.

Articol 22

Emel Ece, Halil Ugur Tasdemir, Recep Biyik, Ayhan Ozmen, Ulku Sayin, Paramagnetic characterization and dosimetric properties of Airfix drug and its ingredients (Montelukast sodium, Sorbitol): An EPR and DFT study, Radiation Physics and Chemistry 195 (2022) 110082, doi: https://doi.org/10.1016/j.radphyschem.2022.110082

Abstract

Paramagnetic characterization and dosimetric properties of Airfix drug and its ingredients (Montelukast sodium, Sorbitol): An EPR and DFT study

Emel Ece [a,b,*], Halil Ugur Tasdemir [c], Recep Biyik [d], Ayhan Ozmen [e,f], Ulku Sayin [e,f]

[a] Karamanoğlu Mehmetbey University, Kamil Özdağ Faculty of Science, Dept. of Physics, Karaman, Turkey
[b] Selçuk University, Institute of Science, Department of Physics, Konya, Turkey
[c] Necmettin Erbakan University, Ahmet Keleşoğlu Faculty of Education, Physics Ed. Dept, Konya, Turkey
[d] Turkish Energy, Nuclear and Mineral Research Agency, Nuclear Energy Research Institute, Istanbul, Turkey
[e] Selçuk University, Faculty of Science, Department of Physics, Konya, Turkey
[f] Selçuk University, Advanced Technology Research and Application Center, Konya, Turkey

ARTICLE INFO

Keywords:
EPR Dosimetry
Density functional theory (DFT)
γ-irradiation
Alkyl radical
Montelukast sodium
Sorbitol

ABSTRACT

In this study, radiation effect on an asthma drug Airfix and its ingredients (Montelukast sodium, Sorbitol) were analyzed by using EPR spectroscopy in the dose range of 10 Gy–30 kGy. The dependence of radiation-induced radicals on irradiation dose, temperature and time was investigated in detail. It has been determined that the radical observed predominantly in the Airfix structure originates from Sorbitol, and the characteristic features of this alkyl-type radical have been clearly defined using both experimental EPR and theoretical DFT methods. Dosimetric properties were investigated for all samples and it was suggested that Airfix drug and Sorbitol could be used as an EPR dosimeter through this radical agent which was determined to be very stable and sensitive to radiation. Moreover, it has been emphasized that other drugs containing Sorbitol excipient can also be used for dosimetric purposes in the dose range studied and even irradiation doses can be detected in case of radiation sterilization.

Concluzii

4. Conclusions

As a result of this study;

(1) It has been understood that the radiation-induced radical observed predominantly in the Airfix drug originates from the excipient Sorbitol.

(2) Although a radical is formed in the active ingredient Monte with the effect of irradiation; It has been determined that it cannot be used for dosimetric purposes, since the radiation dose dependence of the EPR signal intensity does not fit any function, that is, the radical concentration does not increase significantly with radiation.

(3) It has been determined that an alkyl type radical is formed by the breaking of a hydroxyl group in the structure of the irradiated Sorbitol molecule. By experimental measurements and ab-initio calculations, the spectroscopic splitting factor (g) known as the radical fingerprint, and the hyperfine structure constant (a) which is proportional to the distribution of the unpaired electron density on the atoms, were determined. Therefore, the identity of the radical has been precisely defined and the importance of using EPR and DFT studies together in radical characterization has been demonstrated once again.

(4) For the first time, this study showed that the radiation-induced alkyl-type radical in Sorbitol has a linear dose dependence over a wide dose range (from 10 Gy to 30 kGy). In addition, it has been determined that this radical can be detected at room temperature for at least two years with almost the constant signal intensity, that is, it is quite stable. These valuable results will make an important contribution to the information presented in the literature about Sorbitol.

(5) Since the radical formed in Sorbitol is linear sensitive to radiation and has a very long lifetime (an important requirement for a

dosimeter), both this molecule itself and the drugs in which it is an excipient (such as Airfix) can be used reliably as retrospective/accidental EPR dosimeters (with MDD value 3 ± 0.5 Gy). Moreover, whether drugs containing this excipient are sterilized or not, and if so, the sterilization dose value can be determined by this radical.

(6) Sorbitol molecule, which is a pharmacologically inactive substance, is a sugar alcohol that is widely used as a sweetener or humectant in the pharmaceutical, cosmetic and food industries. For this reason, it is thought to be important to recommend this molecule as a retrospective/accidental EPR dosimeter in cases of unwanted radiation exposure in all areas where nuclear applications (research, industrial, medical, forensic, energy, nuclear weapons, etc.) are made.

Articol 23

Einar Sagstuen, Veronika Kugler, Eli Olaug Hole, Anders Lund, Radicals in ammonium tartrate at 295 K by X-radiation: Revised radical structures by EMR and DFT analyses, Radiation Physics and Chemistry 196 (2022) 110097, doi: https://doi.org/10.1016/j.radphyschem.2022.110097

Abstract

Radicals in ammonium tartrate at 295 K by X-radiation: Revised radical structures by EMR and DFT analyses

Einar Sagstuen [a,*], Veronika Kugler [a,b,1], Eli Olaug Hole [a], Anders Lund [b]

[a] Department of Physics, University of Oslo, 0316, Oslo, Norway
[b] Department of Physics, Chemistry and Biology, Linköping University, 581 83, Linköping, Sweden

ARTICLE INFO

Keywords:
Electron paramagnetic resonance
Electron magnetic resonance
Ammonium tartrate
Radiation induced radicals
Ionizing radiation
EPR dosimetry
Periodic DFT

ABSTRACT

The simple amino acid l-α-alanine (*ala*) in polycrystalline form was among the first substances to be proposed and subsequently developed for Electron Paramagnetic Resonance (EPR)-based solid state radiation dosimetry. One disadvantage with *ala* is a relatively low sensitivity for doses below a few gray (Gy) which is a dose range of particular interest in medical, accident and environmental applications. A number of other compounds have been screened and some of these have shown a better sensitivity to radiation exposure than *ala*, in some cases up to a factor of 7–8. In particular ammonium tartrate (AT) and lithium formate (LiFo) have been taken into practical use. The present work was initially aimed to investigate the low-temperature radical products in AT, and the reactions leading to the product of dosimetric interest at room temperature. As a part of these studies, the previously characterized major room temperature radical product was re-investigated using single crystal electron magnetic resonance (EMR) techniques combined with periodic density functional theory (DFT) -type quantum chemical calculations. Surprisingly, this study showed that the molecular structure of the dominant radical at room temperature is somewhat different from that previously proposed. Furthermore, a second room temperature radical, previously not well characterized, was carefully investigated and three hyperfine coupling tensors were determined. These three tensors were sufficient to simulate all experimental observations for the second radical but not alone sufficient to permit an unambiguous molecular structure of the defect to be determined. It appears that the EPR resonance from this radical does not influence the dosimetric potential of AT.

Concluzii

4. Conclusions

In the present work the room temperature radical formation in di-ammonium tartrate crystals has been reinvestigated using EPR, ENDOR, EIE and DFT methods. It has been shown that the dominant radical (**R1**) of dosimetric interest is a species formed by a net H-abstraction from the C3 carbon atom of the tartrate backbone. This reassignment of the radical structure as compared to previous analyses (Brustolon et al., 1996) has no influence on the use of AT as a radiation dosimeter. It has further been demonstrated that a second radical (**R2**) is stabilized at room temperature. Even if the experimental data for this species are comprehensive, a definitive structural assignment could not be made. The major proton coupling characterizing radical **R2** (i.e. the largest doublet splitting) is sufficiently large for the resonance spectrum of this defect not to overlap the major resonance used for dosimetry purposes to any significant degree Preliminary low temperature measurements indicate that a protonated anion radical and a decarboxylated cation radical are the most prominent primary radicals formed.