Absolute dose rate: Comparison of results and uncertainty analysis of a) using a chamber calibrated in air (A-20 from Standard Imaging calibrated on ADCL Wisconsin, USA) following the AAPM TG-61 protocol, and b) using a parallel plate chamber calibrated in water (TM34013 from PTW calibrated on PTW, Germany) following the IAEA TRS-398 protocol.
PDD: Using the parallel plate chamber on solid water.
Leakage: Measurements at different levels with the primary beam blocked
The Esteya includes a specially designed QA tool that is connected to the exit of the X-ray tube. Each treatment day it is mandatory to perform a QA test before the first patient can be treated. This tool is composed of 26 diodes placed in two parallel planes, which are used to evaluate the output, flatness and percentage dose depth curve constancy at the same time. After the QA plan has been irradiated, the equipment console automatically shows the comparison with the reference values. Only if results are below an established tolerance level, the system allows patients to be treated. In addition, within a monthly basis, flatness, symmetry, penumbra, output and PDD are evaluated with film or high resolution array and parallel plate chamber on solid water.
Finally, the following clinical implementation aspects will be presented and discussed: depth evaluation (using High Frequency Ultrasound), margins and applicator selection, patient marking, patient set-up and treatment time calculation.

SP-0600
Reference and relative dosimetry for kV x-rays in radiotherapy
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Background/Objective: Low and medium energy (kV) x-ray radiotherapy beams are still widely used for treatment, particularly for skin cancers and other relatively shallow lesions, and also more recently for 'electronic brachytherapy' (Perez-Calatayud, this session). Historically, kV beams have been used widely for radiobiology and related experiments, the results of which have been used to inform clinical radiotherapy practice, although the dosimetry has often been on less solid foundations than radiotherapy dosimetry. In the last ten years or so, since the increasingly wide availability of kV image guidance systems on clinical linacs, there has been a growing need for clear recommendations on kV beam dosimetry for these systems, where practical approaches have been developed which draw on both diagnostic radiology dosimetry and kV therapy beam dosimetry and with signficant contribution from MC modelling (Ding, this session). Recently too, kV applications relevant to radiotherapy, in terms of supporting and developmental research, have included pre-clinical studies using small animal irradiators and microbeam methods, in both cases requiring small (or very small) kV beam dosimetry. In general terms, the same quality standards are applicable in kV dosimetry as for high energy (MV) x-ray beams. Thus, ideally, similar levels of precision and accuracy are required for treatment planning and delivery and hence similar levels of knowledge of beam characterisics and kV beam doses for both clinical and research uses, including for radiotherapy imaging beams. Therefore, similar attention is necessary in choice of instrumentation, experimental methods, beam calibration dosimetry, beam commissioning and quality assurance measurements, and their uncertainties. kV beams should also be consisdered, as for MV beams, within the same general infrastructure of radiotherapy quality systems, clinical/quality audit and dosimetric audit.
Overview Content: This overview considers the current situation in kV radiotherapy beam dosimetry and aims to cover:
- an outline of the specific requirements in kV dosimetry
- the instrumentation requirements for absolute and relative dose measurements in therapy beams
- the current dosimetry protocols and their similarities and differences, both for beam calibration protocols (in air and in phantom) and relative dosimetry recommendations
- phantoms and methods for measurements
- the likely uncertainties involved in methods and data
- the differences and similarities between dosimetry for kV beams when used for therapy or imaging
- the dosimetry methods used for kV CBCT
- MC in kV dosimetry, linking to Ding (this session)
- some comments on dosimetry needs and methods for novel kV applications, including small animal systems and microbeams.

Conclusions: The basis of kV dosimetry and the practical methods used are reasonably consistent with MV dosimetry, although uncertainties are typically greater. Radiotherapy imaging dosimetry methods span different approaches which still needs further effort to agree generally recommended and accepted guidelines. Recent developments in pre-clinical and microbeam applications have concentrated effort on small field kV dosimetry, which in turn also improves dosimetry for standard clinical uses of kV radiotherapy beams. All areas of kV beam dosimetry are benefiting greatly from MC modelling.

SP-0601
Monte Carlo simulations of kV imaging beams and methods of managing imaging doses to radiotherapy patients:
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Introduction: The utilization of kV X-ray in image-guided radiotherapy (IGRT) has significantly improved the radiotherapy delivery accuracy and IGRT has become the new paradigm for patient positioning and target localization. Daily imaging procedures also add additional dose to the patients' normal tissues. Knowledge of radiation dose resulting from a kV-CBCT scan and kV radiograph imaging procedures is important for clinicians in making informed decisions for treatment management and risk/benefit analysis.
Purpose: The purpose of this presentation is
1) to describe the Monte Carlo simulation technique to generate kV beams from x-ray sources that are integrated to a radiotherapy treatment unit;
2) to show the beam characteristics of kV beams used in image guidance procedures;
3) to present the techniques to calculate dose to patients from kV-CBCT scans and kV radiograph imaging procedures by using the simulated kV beams
4) to give overview of Radiation dose to patients resulting from typical image-guided procedures
5) To discuss methods of managing and accounting for imaging guidance doses to radiotherapy patients
Methods and Materials: Although new model based calculation algorithms are being developed for model the radiation dose from low-energy x-ray beams, the Monte Carlo

technique is regarded as the most accurate calculation method in the dose calculations for kV beams. The Monte Carlo user code, BEAMnrc/DOSXYZnrc was used to simulate x-ray sources. The detailed x-ray tube geometry was simulated, including the anode x-ray tube specifications, target design, beam definition, beam filtration systems, and incident electron energy. Each simulated realistic kV beam with respect of an image acquisition procedure was stored in a phase-space file. The simulated beam specific to an image procedure was individually calibrated by using anl ion chamber in which the air kerma calibration factor is traceable to national standards. When a Monte Carlo simulated beam is calibrated it allows the user to calculate both relative and absolute absorbed doses to patients. Patient dose calculations were done using the Monte Carlo generated kV beam as an incident beam on patient CT based images. The dose resulting from a radiograph image procedure was calculated by incident the source from a fixed incident angle (AP, RL, etc.) while the dose resulting from a kV-CBCT scan was calculated by rotating the X-ray source around the patient based on the specific scan procedure.

Results: The Monte Carlo simulation provides realistic beam details such as energy spectra, particle fluence, and the mean energy distributions. The simulation accuracy was validated by benchmarking the Monte Carlo simulations against measurements of the beam's half-value layers and dose distributions. Patient dose calculations showed that the imaging doses to the eyes for representative head images are 0.05-0.2 cGy and 0.1 cGy; doses to the bladder for representative pelvis images are 1.6 cGy and 0.07 cGy; while doses to the heart for representative thorax images are 0.4 cGy and 0.07 cGy; when using kV-CBCT scans and kV radiographs, respectively. In contrast, organ doses increase by a factor of 2-4 if bow-tie filters are not used during kV-CBCT acquisitions.

Conclusion: The excellent agreement between Monte Carlo calculations and measurements demonstrates that Monte Carlo techniques yield accurate results for kV dose calculations. Current on-board kV imaging devices result in much lower imaging doses compared to the conventional MV portal imagers. There are a variety of approaches available to significantly reduce the image doses. It is feasible to estimate and account for organ dose by using tabulated values based on scan procedure and site because organ doses from imaging procedures are only modestly dependent upon scan location and body size.

Symposium: Innovations in functional imaging for radiotherapy

SP-0602

PSMA ligands for diagnosis and therapy

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Since the prostate-specific membrane antigen (PSMA) is frequently over-expressed in prostate cancer (PCa) several PSMA-targeting molecules are under development to detect and treat metastatic castration resistant prostate cancer.

In 82.8% of 319 patients investigated with ^{68}Ga-PSMA^{HBED}-PET/CT at least one lesion indicative for PCa was detected. Tumor detection was positively associated with PSA level and androgen deprivation therapy. Amongst lesions investigated by histology, 30 were false-negative in ^{68}Ga-PSMA^{HBED}-PET/CT (one local relapse in one patient and 29 lymph nodes in another patient), all other lesions (n=416) were diagnosed true-positive or -negative. Fifty of 116 patients available for follow-up received local therapy after ^{68}Ga-PSMA^{HBED}-PET/CT.

A comparison of ^{68}Ga-PSMA-ligand with ^{18}F-fluoromethylcholine PET/CT revealed 78 PC-suspicious lesions in 32 patients using ^{68}Ga-PSMA-PET/CT and 56 lesions in 26 patients using Choline-PET/CT. The higher detection rate in ^{68}Ga-PSMA-PET/CT concerning PC-suspicious lesions was significant (p=0.04). All lesions detected by ^{18}F-fluoromethylcholine-PET/CT were also seen by ^{68}Ga-PSMA-PET/CT. In ^{68}Ga-PSMA-PET/CT SUV_{max} was clearly (>10%) higher in 62 of 78 lesions (79.1%) and tumor-to-background ratio was clearly (>10%) higher in 73 of 78 lesions (93.6%) when compared to ^{18}F-fluoromethylcholine-PET/CT.

Since the ligand bound to PSMA is internalized, the target may also be used for endoradiotherapy. We used a small molecule inhibitor of PSMA ((*S*)-2-(3-((*S*)-1-carboxy-5-(3-(4-[^{131}I]-iodophenyl)ureido)-pentyl)ureido)-pentanedioic-acid; MIP-1095) for therapy in men with mCRPC. Dosimetry estimates for I-131-MIP-1095 revealed that the highest absorbed doses were delivered to the salivary glands (3.8 mSv/MBq, liver (1.7 mSv/MBq) and kidneys (1.4 mSv/MBq). The absorbed dose calculated for the red marrow was 0.37 mSv/MBq. PSA values decreased by >50% in 60.7% of the men treated. 84.6 % of men with bone pain showed complete or moderate reduction in pain. Hematological toxicities were mild. 25% of men treated had a transient slight to moderate dry mouth. No adverse effects on renal function were observed.

In order to increase the therapeutic flexibilty we designed a novel theranostic PSMA ligand coupled to DOTA which allows coupling to Ga-68 for diagnostic use or to Lu-177 or Ac-225 for therapy. Especially for alpha therapy with Ac-225 promising results were found in the first 10 patients.

SP-0603

MR spectroscopic imaging at high field for tumour characterisation

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Abstract not received.

SP-0604

A visual computing approach towards integration of multi-parametric imaging into radiation oncology workflows

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The integration of the full analytical power of today's multi-modal and multi-parametric imaging techniques into workflows of radiation oncology has not yet reached daily clinical routine. Reasons for this are manifold and range from simple data integration problems to the question, how the relevant information distributed over different images or over several parameters can be fused in the best way to provide a more complete and comprehensive image of the current situation.

The EU project Software for the Use of Multi-Modality images in External Radiotherapy – SUMMER(*) is addressing these problems with the aim to extend the current set of imaging modalities integrated into radiotherapy planning. In this talk, I will give an overview over faced challenges and results achieved over the last 3 years from a Visual Computing perspective. I will show how visualization, data fusion, and alternative ways in data representation can be used to gain