Physica Medica xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Physica Medica

journal homepage: http://www.physicamedica.com

Original paper

# Imaging practices and radiation doses from imaging in radiotherapy

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ARTICLE INFO

*Article history:*
Received 30 December 2016
Received in Revised form 21 February 2017
Accepted 19 March 2017
Available online xxxx

*Keywords:*
Radiotherapy
Imaging
Out-of-field dose
IGRT

ABSTRACT

Modern radiotherapy treatments require frequent imaging for accurate patient positioning relative to the therapeutic radiation beam. Imaging practices in five Finnish radiotherapy clinics were assessed and discussed from the patient dose optimization point of view. The results show that imaging strategies are not jointly established and variations exist. The organ absorbed doses depend on imaging technique and imaging frequency. In particular, organ doses from the cone beam computed tomography can have very large variations (a factor of 10–50 in breast imaging and factor of 5 in prostate imaging). The cumulative imaging organ dose from the treatment can vary by a factor of ten or more for the same treatment, depending on the chosen technique and imaging frequency. Awareness and optimization of the imaging dose in image-guided radiotherapy should be strengthened.



## 1. Introduction

Radiation therapy with highly conformal and dynamic beams has become a routine in treatment of cancer. These treatment techniques require accurate patient positioning and tumor localization to have a maximal benefit from the treatment and to minimize harmful side effects such as excessive damage of nearby healthy tissues. Image-guided radiotherapy (IGRT) is a well-established approach and is increasingly used for positioning and target localization during the treatment. Several technical imaging solutions are available, including kilo- and megavoltage radiographs (portal imaging) and cone beam computed tomography (CBCT). The portal imaging uses the MV therapeutic beam itself, while the CBCT can use either kilo- or megavoltage beam. Imaging with the kV photons requires a dedicated imaging device.

Contribution from the imaging to the patient dose depends on the imaging technique, imaging parameters, imaged region and imaging frequency during the treatment process. Studies have been published on patient dosimetry and comparison between different techniques, see e.g. [1,2]. These studies show that generally highest organ absorbed doses (in the imaged region) per imaging session are caused by MV portal imaging, followed by kV CBCT. Lowest organ doses per image result from the kV radiographs.

If imaging is used frequently and without optimization of the imaging parameters, out of field doses, i.e. outside the planning target volume (PTV), from imaging can be comparable to dose from the scatter and leakage radiation associated with the therapeutic beam [3]. As there is a clear evidence [4–6] of induction of secondary cancers (outside the PTV) following external beam radiotherapy, the dose contribution from the imaging should be taken with due respect. For example, doses to contralateral breast and lung and the associated risk of secondary cancer has received attention (see e.g. [5]). Especially the use of portal imaging and non-optimized CBCT may result in substantial doses to these organs. In the PTV, the organ doses from imaging can approach 1–2% of the therapeutic dose [2,7], if used carelessly. While this may not be critical for the success of the treatment, it is sometimes taken into account in the treatment planning to allow a better consistence with the 5% accuracy requirement of the dose delivery to the target [8,9]. Higher accuracy requirements have been also discussed [10]. This additional dose may also push organs at risk close to PTV above the set dose tolerances. At the same time, imaging is crucial for the success of modern complex and dynamic treatments. Without frequent imaging the accurate beam positioning is not possible.

With a careful optimization of imaging, the organ doses can be reduced to a small fraction of the above mentioned level. The optimization of the imaging includes the practices how (or how often) actual imaging is carried out – is localization verification needed at every fraction or can less imaging be used without compromising the accuracy of the patient positioning? Is the kV radiograph sufficient or is the CBCT needed? Significant variations in dose levels between different equipment manufacturers are also possible [2]. As an example, the use of bowtie filter in CBCT has potential for significant dose reduction [1].

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http://dx.doi.org/10.1016/j.ejmp.2017.03.012
1120-1797/

Published recommendations of good imaging practices in IGRT are scarce. For example, ESTRO-EIR [11] and The Royal Australian and New Zealand College of Radiologists [12] speak in favor of 3D imaging, but detailed recommendations for actual practice are not given. In Finland all radiotherapy centers are obliged to participate in clinical audits where clinical practices are analyzed by an independent expert group. Finnish advisory committee for clinical audit has given suggestions and a baseline documentation for an audit of radiotherapy treatment of breast cancer [13]. This includes also the suggestions for good imaging practices in IGRT. There, in addition to a weekly oblique projection, an AP projection is suggested for patients with metastases in nearby lymph nodes. In deep inspiration breath hold treatments (DIBH) daily imaging is suggested. No further suggestions were given for imaging modalities.

In this study, imaging practices at several Finnish radiotherapy clinics were assessed. Information about imaging techniques, parameters and frequencies were collected for external beam radiotherapy treatments of prostate and breast radiotherapy after mastectomy. Comparison between imaging practices is presented and the results are discussed from the patient dose optimization point of view.

## 2. Materials and methods

An email questionnaire was sent to eight Finnish radiotherapy clinics (to medical physicists who are involved with the treatment planning, quality assurance and radiological protection of the patients). This included five university hospitals (UH) and three central hospitals (CH). Five answers were received, three from UH and two from CH. The biggest contributing clinic was a university hospital with ten linear accelerators whereas the smallest central hospital has two linear accelerators. The clinics were geographically evenly distributed in Finland. No patient specific data were collected i.e. it was assumed that the primary imaging protocols do not significantly vary from patient to patient.

The topics covered by the questionnaire were

- Equipment: manufacturer, model, version
- Imaging technique used (kV radiograph, MV portal imaging, kV and MV CBCT, MV CT)
- Imaging techniques used at each fraction and the number of images per fraction (specify projections in radiographs and MV portal imaging)
- Total number of images taken during the whole treatment
- Typical imaging parameters, separately for each modality and projection (in planar imaging)
  - o kV radiograph: Tube current, time, tube voltage, filtration, focus-skin or focus-detector distance, imaged region (dimensions)
  - o CBCT: Rotation angle of the tube, current-time product per projection, $CTDI_w$, is the bowtie filter used, number of projections, length of the imaged region, focus to isocenter distance
  - o MV portal imaging: Monitor units, imaged region (dimensions), distances

The clinics were asked to answer the questionnaire based on the two most frequent treatments, i.e. cancers of prostate and breast. Results from different clinics were analyzed and a comparison was made between the clinics.

The dose estimates from imaging were based on Monte Carlo simulations using the ImpactMC program, version 1.4 (GPU version) [14] and the PCXMC program [15] (for kV radiographs in prostate treatments). In dose simulations with ImpactMC a CT image of an anthropomorphic adult female phantom (CIRS ATOM 702-D, Norfolk, USA) was used with a 2.5 mm slice thickness. Therefore, the dose estimates are not patient specific and represent a general level of exposure, typical for the imaging modality in question. The rotation isocentre in CBCT simulations was just below the breast, close to the chest wall and at the position of prostate. Detailed information on the bowtie filter geometry of each CBCT scanner was not available. Therefore, a common approximate model of a bowtie filter was used based on information obtained from CH2. The impact of this approximation on organ doses was estimated with comparing calculations with and without the bowtie filter, providing a maximum deviation for the dose. In cases where the rotation angle of X-ray tube was reduced, it was assumed that the tube rotated above the patient. For the kV radiography the incident air kerma was estimated with PCXMC program based on the kV, filtration, exposure time and tube current values. PCXMC was also used to produce the X-ray spectra for the simulations. In cases where clinics indicate AP or PA projection for kV radiographs, organ doses were calculated only for AP projection. In addition, the doses were simulated for treatments of left breast.

The CIRS phantom does not have all the internal organs of interest. Thus, the location of the rectum and the urinary bladder was deduced from the organ positions in ICRP standard phantom [16] and in MIRD-type phantom as implemented in the PCXMC program [15]. The organs of interest were manually segmented in each slice with ImageJ software [17]. The organ doses were obtained from these slice-by-slice segmentations as area-weighted mean pixel values (normalized doses) that were exported as DICOM files from ImpactMC. ImageJ was used to calculate the mean values. In PCXMC calculations the dose to the rectum was taken to be the dose to the lower large intestine.

The phantom model did not define the red bone marrow (RBM) as a separate tissue but as a mixture of cortical bone, spongiosa and bone marrow. The absorbed dose to RBM in a bone can be approximated from the dose to the bone multiplied by the mass energy absorption coefficient ratio of RBM to mean bone material. An average value over the photon energy range 20–150 keV was used, resulting in a correction factor 0.48. The RBM composition was assumed to be equal to that of the soft tissue.

Due to abovementioned approximations the CBCT dose levels reported have an estimated standard uncertainty of 20% when applied to average-sized patients. The main components in uncertainty budget were the estimation of air kerma at the isocentre needed for the input of ImpactMC simulation (15%) and the dose modifying effect of the bowtie filter (10%). Other components were the statistical uncertainty of dose simulations (6%), the uncertainty associated with the organ segmentation and the corresponding dose averages for each slice (5%). For the RBM dose an additional 10% uncertainty component stems from the conversion from the dose to the bone.

In kV radiograph simulations using ImpactMC the uncertainty components were the statistical uncertainty (4–30%) and the segmentation (5%), yielding a total of 6–30%. The highest uncertainties were for the organs outside the primary beam and with very low doses, i.e. contralateral lung and breast. The statistical uncertainty in PCXMC simulations was less than 3%.

## 3. Results

The data covered 19 linear accelerators of Varian Medical Systems and 3 accelerators manufactured by Elekta AB. The oldest accelerators included in the data were installed in 1993. MV CT or MV cone beam CT were not available in any clinic.

The CBCT technique is available at every clinic that participated in this study. However, some clinics apply it routinely whereas some clinics use it very sparingly, only in very specific cases a

Please cite this article in press as: Siiskonen T et al. Imaging practices and radiation doses from imaging in radiotherapy. Phys. Med. (2017), http://dx.doi.org/10.1016/j.ejmp.2017.03.012