Radiotherapy and Oncology 124 (2017) 147–154

Contents lists available at ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

Esophageal cancer

Interfractional variability of respiration-induced esophageal tumor motion quantified using fiducial markers and four-dimensional cone-beam computed tomography

Peng Jin *, Maarten C.C.M. Hulshof, Niek van Wieringen, Arjan Bel, Tanja Alderliesten

Department of Radiation Oncology, Academic Medical Center, University of Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 29 August 2016
Received in revised form 18 May 2017
Accepted 21 May 2017
Available online 1 June 2017

Keywords:
Esophageal cancer
Radiation therapy
Fiducial marker
Interfractional variability
Respiration-induced motion
4D-CBCT

ABSTRACT

Purpose: To investigate the interfractional variability of respiration-induced esophageal tumor motion using fiducial markers and four-dimensional cone-beam computed tomography (4D-CBCT) and assess if a 4D-CT is sufficient for predicting the motion during the treatment.

Materials and methods: Twenty-four patients with 63 markers visible in the retrospectively reconstructed 4D-CBCTs were included. For each marker, we calculated the amplitude and trajectory of the respiration-induced motion. Possible time trends of the amplitude over the treatment course and the interfractional variability of amplitudes and trajectory shapes were assessed. Further, the amplitudes measured in the 4D-CT were compared to those in the 4D-CBCTs.

Results: The amplitude was largest in the cranial–caudal direction of the distal esophagus (mean: 7.1 mm) and proximal stomach (mean: 7.8 mm). No time trend was observed in the amplitude over the treatment course. The interfractional variability of amplitudes and trajectory shapes was limited (mean: $\leq$1.4 mm). Moreover, small and insignificant deviation was found between the amplitudes quantified in the 4D-CT and in the 4D-CBCT (mean absolute difference: $\leq$1.0 mm).

Conclusions: The limited interfractional variability of amplitudes and trajectory shapes and small amplitude difference between 4D-CT-based and 4D-CBCT-based measurements imply that a single 4D-CT would be sufficient for predicting the respiration-induced esophageal tumor motion during the treatment course.

© 2017 Elsevier B.V. All rights reserved. Radiotherapy and Oncology 124 (2017) 147–154

Combined with concurrent chemotherapy, radiation therapy (RT) has become standard as part of neoadjuvant or definitive therapy for esophageal cancer [1,2]. How to cope with the uncertainties in tumor delineation, interfractional tumor position variation, and intrafractional tumor motion such as respiration-induced motion, is one concern for RT of esophageal cancer [3]. With the evolution from three-dimensional (3D) conformal RT to intensity-modulated RT and volumetric-modulated arc therapy, with which a more conformal dose distribution can be obtained [4–6], it becomes more crucial to deal with these uncertainties to ensure accurate delivery of the dose to the target volume while sparing the organs at risk as much as possible [7].

Respiration-induced esophageal tumor motion is one of the major sources of intrafractional uncertainties. The quantification of this motion was, until recently, mainly done by measuring the displacement of the delineated gross tumor volume or anatomical landmarks in the 4D computed tomography (4D-CT) data, in spite of the limited soft-tissue contrast of the 4D-CT [8–10]. Since the endoscopy-/endoscopic ultrasound (EUS)-guided implantation of fiducial markers in the volume of esophageal tumor was successful and no migration of fiducial markers was found during the treatment course [11,12], the quantification of the respiration-induced esophageal tumor motion using fiducial markers and 4D-CT became more accurate [13,14]. In these studies, however, the respiration-induced esophageal tumor motion was measured only within one 4D-CT acquisition per patient and the interfractional variability of the respiration-induced motion has not yet been investigated.

Apart from 4D-CT, 4D cone-beam CT (CBCT) can be used for quantifying the respiration-induced tumor motion, as done previously for lung tumors [15,16]. This allows the quantification of the daily respiration-induced tumor motion. However, 4D-CBCT has not yet been commonly introduced in esophageal cancer RT. Recently, a phantom study compared the visibility of gold markers in the 4D-CBCTs acquired using multiple settings by altering the

* Corresponding author at: Department of Radiation Oncology, Academic Medical Center, University of Amsterdam, Meibergdreef 9, 1105 AZ Amsterdam, The Netherlands.
E-mail address: p.jin@amc.uva.nl (P. Jin).

http://dx.doi.org/10.1016/j.radonc.2017.05.015
0167-8140/© 2017 Elsevier B.V. All rights reserved.

dose, gantry rotation speed, and fluoroscopy projection image number. It has demonstrated that fiducial markers can be sufficiently visible in the 4D-CBCTs reconstructed using the same fluoroscopic projection images as used for a clinical 3D-CBCT reconstruction [17]. High accuracy of using the fiducial markers to manually quantify the respiration-induced motion was also shown regardless of the 4D-CBCT acquisition settings.

The aim of this study was to investigate the interfractional variability of respiration-induced esophageal tumor motion using fiducial markers and 4D-CBCT scans which were retrospectively reconstructed using the projection images of the clinical 3D-CBCT scans. Using these data, we verified whether a single measurement based on the 4D-CT acquisition [14] is a good predicator for the respiration-induced tumor motion during the treatment course (i.e., has a small difference from the measurements based on the 4D-CBCT).

Materials and methods

Patients and markers

We included 24 esophageal cancer patients with implanted gold markers, who were also included in former studies [11,12,14]. Two different types of gold markers were implanted: a solid marker (Cook Medical, Limerick, Ireland; or in–house manufactured) and a flexible coil-shaped marker (Visicoil; IBA Dosimetry, Bartlett, TN, USA) [11]. For each patient, 2–5 markers were placed at the cranial and caudal border of the primary tumor and, preferably, in the center of the tumor. The details of the patients and markers are listed in Table 1. In total, 63 markers remained visible in the reconstructed 4D-CBCTs over the whole treatment course. They were categorized according to the American Joint Committee on Cancer manual [18] into four subgroups based on the region of the esophagus in which the marker was located: proximal esophagus (n = 13), middle esophagus (n = 10), distal esophagus (n = 28), and proximal stomach (n = 12), as previously illustrated [12,14].

Within eight days (median: one day) after marker implantation, a 3D planning-CT (pCT) was acquired for each patient (LightSpeed RT 16 CT; General Electric, Waukesha, WI, USA). All patients underwent the scanning in head-first supine position with an arm and knee support (CIVCO Medical Solution, Rotterdam, The Netherlands). The thickness of the CT slices was 2.5 or 3.0 mm and the in-plane pixel size was 1.0, 1.2, or 1.3 mm depending on the field of view (FOV) of the scan. For 16 out of the 24 patients, who were previously included in [14], 4D-CT was acquired in addition to the pCT (Table 1). The 4D-CT acquisition details can be found in [14].

Prior to the treatment fractions, 3D-CBCT scans were routinely acquired following an online setup verification protocol (for patients 10, 23, and 24) or an extended no action level (eNAL) setup verification protocol [19] (for the remainder of the patients) based on bony anatomy (i.e., vertebrae). When the eNAL protocol was used, daily 3D-CBCTs were acquired for the first four fractions, followed by once-weekly acquisitions. Additional 3D-CBCT scans were acquired when the setup correction exceeded the tolerance in the NAL phase. Consequently, 7–28 (median: 8) 3D-CBCT scans were obtained for each patient. During pCT/3D-CBCT scanning and treatment, all patients were freely breathing without receiving any training, coaching or feedback related to achieving a stable breathing pattern.

4D-CBCT reconstruction

4D-CBCTs were reconstructed retrospectively using the available fluoroscopic projection images of the clinical 3D-CBCT scans. These clinical 3D-CBCT scans were acquired using the CBCT imaging units mounted on linear accelerators (Synergy; Elekta, Crawley, UK). Approximately 660 fluoroscopy projection images were collected over a full arc of 360° with a shifted detector, yielding a medium FOV of 410 × 410 mm^2 in the axial plane.

The breathing signal was automatically extracted by detecting the position of diaphragm-like features in the projection images based on the so-called Amsterdam Shroud algorithm (MATLAB 2013b, The MathWorks Inc., Natick, MA, USA) [20]. All projection images were then sorted and reconstructed in ten breathing phases (0–90%) to obtain the 4D-CBCT (i.e., ten 3D-breathing-phase scans) with an isotropic 1.0 mm voxel size using X-ray Volume Imaging software (XVI 4.5.0; Elekta) (Supplementary Fig. A1).

Respiration-induced motion quantification

First, each 3D-breathing-phase scan of the 4D-CBCT was rigidly registered to the pCT based on bony anatomy, i.e., vertebrae, in XVI (Supplementary Fig. A1). Using the coordinate system of the pCT as a reference, marker positions in the 4D-CBCT relative to those in the pCT were then obtained by manually registering each 3D-breathing-phase scan to the pCT with respect to the marker centroid using translations only. This was done for each marker separately.

For each 4D-CBCT, the motion trajectory of each marker over the respiration cycle was subsequently depicted by assessing the differences of the ten marker positions relative to the trajectory centroid, i.e., mean marker position. The respiration-induced motion was quantified in the left–right (LR), cranial–caudal (CC), and anterior–posterior (AP) directions, with the positive coordinates to the left, cranial, and anterior. The peak-to-peak amplitude of respiration-induced motion (hereafter referred to as amplitude) was calculated as the maximum position difference of the motion in each direction.

Per marker, the mean and standard deviation (SD) of the quantified amplitudes over all the 4D-CBCT scans were calculated as the representations of the interfractional mean amplitude and interfractional variability of amplitudes, respectively. The interfractional minimum and maximum amplitudes and the range, i.e., difference between maximum and minimum, were also calculated. Moreover, per marker, the SD of the positions at the end of inhalation relative to the trajectory centroid over all 4D-CBCT scans was calculated. The SD of the positions at the end of exhalation relative to the trajectory centroid was also calculated. Both the SDs were considered as measures of the interfractional variability of trajectory shapes since the end of inhalation and the end of exhalation phases are the two extreme breathing phases, which dominantly define the trajectory shape of the respiration-induced tumor motion. Fig. 1 illustrates how these were calculated.

Statistical analysis

Linear mixed-effects models were used in our analyses to account for the intra-patient correlation of the amplitudes due to the different number of markers among the patients by taking the patient identification number as a random effect in all the tested models. Because of the unequal number of CBCTs among the patients, the marker identification number was also taken as a random effect in the models [21].

By taking the number of days after starting treatment, which was derived from the date of CBCT acquisition, as a fixed effect, we investigated whether the amplitudes have a possible time trend over the treatment course. In addition, when taking the interfractional mean amplitude as a fixed effect, we tested whether the interfractional variability of amplitudes and trajectory shapes (i.e., the aforementioned SDs) was linearly correlated with the interfractional mean amplitude by calculating the marginal and

Download English Version:

https://daneshyari.com/en/article/5529512

Download Persian Version:

https://daneshyari.com/article/5529512

Daneshyari.com