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Impact of intravenous contrast used in computed tomography on radiation dose to carotid arteries and thyroid in intensity-modulated radiation therapy planning for nasopharyngeal carcinoma

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ABSTRACT

The aim of this study was to investigate if intravenous contrast injection affected the radiation doses to carotid arteries and thyroid during intensity-modulated radiation therapy (IMRT) planning for nasopharyngeal carcinoma (NPC). Thirty consecutive patients with NPC underwent plain computed tomography (CT) followed by repeated scanning after contrast injection. Carotid arteries (common, external, internal), thyroid, target volumes, and other organs-at-risk (OARs), as well as IMRT planning, were based on contrast-enhanced CT (CE-CT) images. All these structures and the IMRT plans were then copied and transferred to the non–contrast-enhanced CT (NCE-CT) images, and dose calculation without optimization was performed again. The radiation doses to the carotid arteries and the thyroid based on CE-CT and NCE-CT were then compared. Based on CE-CT, no statistical differences, despite minute numeric decreases, were noted in all dosimetric parameters (minimum, maximum, mean, median, D05, and D01) of the target volumes, the OARs, the carotid arteries, and the thyroid compared with NCE-CT. Our results suggested that compared with NCE-CT planning, CE-CT scanning should be performed during IMRT for better target and OAR delineation, without discernible change in radiation doses.

Introduction

Nasopharyngeal carcinoma (NPC) is an endemic malignancy in southern China, Hong Kong, Taiwan, Singapore, and Malaysia.[1,2] Radiation therapy with or without adjunct chemotherapy is the recommended treatment of choice for this highly curable disease.[3] Intensity-modulated radiation therapy (IMRT), in virtue of its superior tumor coverage and dose sparing to adjacent organs-at-risk (OARs), is the standard radiation technique, which was broadly demonstrated by local and international studies.[4-11] Co-registration of images from magnetic resonance imaging and computed tomography (CT) during target contouring and OARs delineation has become the norm. However, the quality of co-registration was usually suboptimal at the cervical region because of the difference in degree of neck flexion during magnetic resonance imaging and planning CT scan. Although this may be improved by the use of autosegmentation in contemporary softwares, the architecture of the primary tumor at the nasopharynx and the involved neck nodes would be altered as well. Injection of iodinated contrast in CT scanning can definitely solve the problem, but this may introduce errors in dose calculation and dose delivery to patients who would be actually treated without any contrast injection. In addition, contrast injection may result in change in dose received by the carotid arteries and the thyroid, which takes up iodine readily compared with other OARs in the head and neck region. In view of this, we carried out a prospective study investigating the effect of CT contrast on the change in radiation dose to the carotid arteries and the thyroid in patients with newly diagnosed NPC treated with radical IMRT.

Methods and Materials

Study design

The study was approved by the local institutional review board before commencement. Patients with newly diagnosed non-metastatic NPC between July 2009 and June 2011 who were scheduled to receive radical IMRT as curative treatment were eligible. Exclusion criteria included poor performance status (Eastern Cooperative Oncology Group ≥2), and suboptimal hematologic and biochemical functions (defined as absolute neutrophil count $< 1.5 \times 10^9$/mL, liver transaminases $> 3 \times$ upper normal limits, and creatinine clearance < 50 mL/min by Cockroft-Gault formula). After written informed consent, all recruited patients underwent CT scanning with their head and neck immobilized by a customized thermoplastic cast and mouthguard. A non–contrast-enhanced CT (NCE-CT) scanning of the head and neck region down to the aortic arch with a slice thickness of 2.5 mm was done afterward. This was

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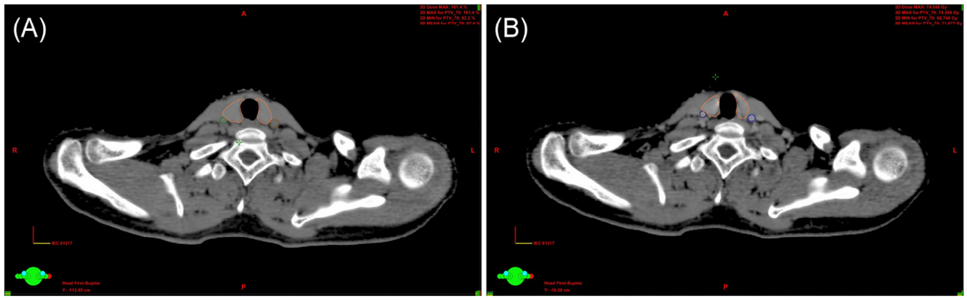

Fig. 1. Computed tomography images of a patient showing the locations of right common carotid artery, left common carotid artery, and the thyroid. (A) Without intravenous contrast injection (right common carotid artery in green, left common carotid artery in brown, and thyroid in orange). (B) With intravenous contrast injection (right common carotid artery in deep blue, left common carotid artery in blue, and thyroid in orange). (Color version of figure is available online.)

immediately followed by injection of 100-mL iopamidol containing 300-mg iodine/mL at a rate of 2 mL/s by an injector and a repeated CT scanning of the same region in the same session without any patient movement. Both NCE-CT and contrast-enhanced CT (CE-CT) images were then transferred to Eclipse Treatment Planning System version 10.0 (Varian Medical Systems, Palo Alto, CA) for target and OARs delineation, as well as dose calculation and IMRT planning. Both the OARs and the target volumes were outlined on CE-CT images as our institutional practice, which were then used for IMRT planning. The critical OARs included brainstem, spinal cord, optic nerves, and optic chiasm, whereas the less important OARs were lenses, temporomandibular joints, temporal lobes, auditory nerves, cochleae, mandible, oral cavity, larynx, parotid glands, and vestibules. Then the gross tumor volumes (GTV) of both the primary tumor and the radiologically involved cervical nodes were outlined as previously described.[12] Subsequently, the clinical target volume (CTV-70) for the microscopic disease spread and the planning target volume (PTV) containing CTV-70 with a 3-mm margin (PTV-70) were generated, taking into account the physiologic body motion and the setup errors. Another CTV-66 encompassing the high-risk areas including the posterior half of the maxillary sinuses, nasal cavities, parapharyngeal spaces, styloid processes, basiocciput, basisphenoid, clivus, foramina rotunda and ovale, pterygopalatine fossae, pterygomaxillary fissures, infraorbital fissures, cavernous sinuses, and level IB and V nodal stations were also outlined subsequently. A corresponding PTV-66 with a 3-mm margin encompassing the CTV-66 was created by Boolean operations of Eclipse Treatment Planning System, which was also used for IMRT planning using analytical anisotropic algorithm. In addition, the carotid arteries including common carotid arteries (from the aortic trifurcation up to its division into external and internal carotid arteries), external carotid arteries (from their origin at carotid bifurcation up to bifurcation into internal maxillary artery and superficial temporal artery), and internal carotid arteries (from their origins at carotid bifurcation up to bifurcation into anterior cerebral artery and middle cerebral artery) on both sides of the neck as well as the whole thyroid gland were contoured. All of the target volumes, OARs, carotid arteries, and thyroid were contoured by the same oncologist (VHFL).

Treatment planning and optimization was carried out by Eclipse Treatment Planning System version 10.0 (Varian Medical Systems). Total doses of 70 Gy and 66 Gy were prescribed to PTV-70 and PTV-66, respectively, delivered in 33 fractions by simultaneous accelerated radiation therapy technique (SMART) with a 6 MV linear accelerator, which has been a standard fractionation scheme used in our institution.[12] The doses constraints to the brainstem, spinal cord, and optic nerves/optic chiasm were limited to 54 Gy, 45 Gy, and 54 Gy, respectively. However, allowances were made in some individual patients whose primary tumors were extremely close or had invaded into these OARs, so that the maximum dose to the brainstem, spinal cord, and optic nerves/optic chiasm were up to 63 Gy, 48 Gy, and 63 Gy, respectively. This was decided after consensus from both the oncologists and the patients, with a slightly increased risk of deterioration of organ functions explained to the patients to ensure adequate coverage to the PTV. Efforts were also made to limit the mean dose to the parotid glands to 26 Gy and the dose to the lenses and temporal lobes to as low as could reasonably be achieved without compromising dose coverage to the PTVs. Upon completion of optimization and acceptance by the treating oncologist, all of the target volumes, OARs, as well as the IMRT plans based on CE-CT images were directly copied and transferred to NCE-CT images (Fig. 1). Dose calculation without optimization was performed again on the NCE-CT images (Fig. 2). All IMRT planning, dose optimization and calculation, as well as quality assurance, were performed by a certified medical physicist, and all IMRT plans fulfilled the acceptance criteria, with at least 95% of PTVs having received the prescribed dose, the maximum dose of PTVs limited to 107% or below, and the maximum dose of OARs within tolerance limits. They were then approved by treating radiation oncologists before IMRT commencement. To track any anteroposterior and lateral body displacements, positional verification with on-board imaging was performed before and then once before the first 3 fractions of IMRT followed by weekly afterward during the whole course of IMRT. Patients with Stage III to IV diseases were given concurrent chemotherapy with cisplatin 100 mg/m^2 on days 1, 22 and 43 of IMRT, followed by adjuvant chemotherapy starting at 4 weeks after completion of IMRT with cisplatin 80 mg/m^2 on day 1 and 5-FU 1000 mg/m^2 from days 1-4 every 4 weeks for 3 more cycles, unless patients refused or they were medically contraindicated to chemotherapy because of significant comorbidities.

Patient characteristics

A total of 30 patients were prospectively recruited, and their baseline characteristics are shown in Table 1. Only 1 patient received IMRT alone because of his extremely advanced age. The remaining 29 patients received concurrent chemoradiation with or without adjunct chemotherapy.

Statistical analysis

The minimum, maximum, mean, median, D05 (the dose received by the maximal 5% of a target volume or an OAR), and D01 (the dose received by the maximal 1% of a target volume or an OAR) of PTV-70, PTV-66, carotid arteries, and thyroid from NCE-CT and CE-CT images were recorded, which were compared by paired t-tests. Statistical significance was defined as $p < 0.05$ (two-sided). All statistical analyses were performed by Statistical Package for Social Sciences version 22.0 (IBM SPSS Statistics for Windows, IBM Corp., Armonk, NY).

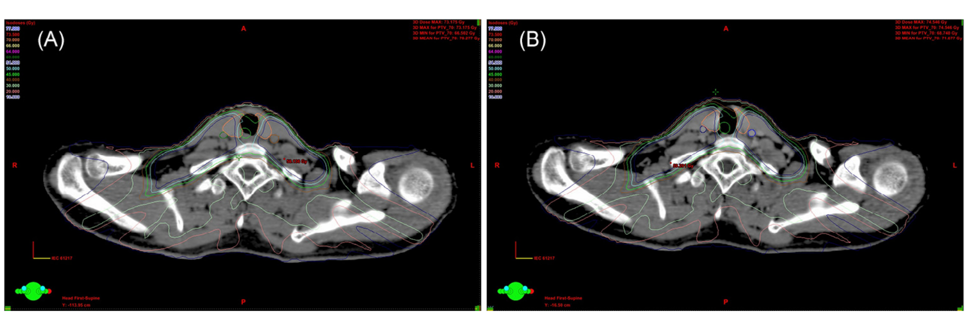

Fig. 2. Isodose distribution of IMRT plans of the same patient showing the radiation doses to the common carotid arteries and the thyroid. (A) NCE-CT images after dose recalculation without optimization from the IMRT plan generated from (B) CE-CT images. (Color version of figure is available online.)