Radiotherapy Treatment Planning in Head and Neck Cancer by CT-Reconstruction

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The ultimate goal of radiotherapy is to result in complete local control of tumor while sparing the surrounding normal tissues as much as possible. Since the development of CT in 1970s, patient's anatomical normal tissues and the site and extent of infiltration of tumor were identified almost accurately. In addition, the isodose distribution of delivered radiation to target tumor was shown in each cross-section. In the treatment planning of head and neck cancers, CT-reconstruction provided almost 3-dimensinonal inter-relationship between tumor and normal tissues. The utilization of imaging system of the CT scanner made it possible to illustrate in superposition the patient structure image, the radiation beams, and the isodose distributions. Thus it was possible to deliver radiation enough to control the local disease, and to avoid unnecessary administration of radiation to normal tissue such as spinal cord. CT-reconstructed image in axial, sagittal, and coronal planes suggested 3-dimensional radiotherapy treatment planning be possible and practical instead of conventional 2-dimensional planning at coronal plane.

Key Words: Radiotherapy treatment planning, CT-reconstruction

INTRODUCTION

The ultimate goal of radiotherapy is to maximize the chance of local control of cancer, while sparing the normal tissues as much as possible to minimize unnecessary morbidity.

The history of radiation therapy treatment planning began in mid-1960s using relatively conventional rudimentary data. By the advent of computed tomography (CT) in 1970s, there was a major breakthrough in delineating the location and extent of tumor and normal tissue concerning the patient's anatomy.

The target volume is then approached with several external beam portals, and the distribution of radiation dose (isodose curve) is adjusted so that the tumor receives as much radiation as possible, and uninvolved normal tissue through which the radiation must pass is spared as much. The treatment plan thus generated can be carried out reproducibly with precision over a planned period.

The improvement in treatment through these advantageous capabilities has been accelerated by many investigators[1~6]. Because the tumors are three-dimensional (3-D) structures with dents and protrusions, we have undertaken studies of the impact of CT scanning upon the radiation therapy treatment planning through observation of the dose distribution by 3-D representation of CT scanning in head and neck cancer patients. Though these were not an integrated display of the multiple sections and did not fit the true meaning of three-dimension, we defined, in convenience, 3-D as the reconstructed CT image in coronal, sagittal, and axial planes. The accuracy in distribution and computation of the dose was excellent.

MATERIAL AND METHOD

Forty-two patients underwent planning CT scan among the registered total head and neck cancer patients in the Department of Therapeutic Radiology, Kyungpook National University Hospital from April 1985 to August 1987

By anatomic grouping, the patients were divided into subgroups according to the principal site of irradiation. This anatomic grouping is illustrated in Table 1. We confined our studies to the patients who were receiving radical therapy with intent to cure and did not include the patients for whom purely palliative therapy was planned.

The study conducted was as follows. The patients were first evaluated with conventional methods, ie, history and pertinent physical examination, results of laboratory studies, review of histopathological materials, and analysis of imaging including diagnostic CT scan to establish diagnosis and tumor stage. Then the treatment goals and radiotherapy plans are decided according to the patient's problem. After selection of the type of treatment, the patient underwent simulation and resulting portal films were obtained. A planning CT scan was performed. Sections were taken at appropriate planes throughout the volume considered for treatment as well as the regions of superior and inferior to the tumor volume. The scanner was GE CT/T8800. The radiotherapist-in-charge and the skillful technologist were always present when the CT scan was obtained. It was essential to position the patient precisely just as the treatment position with radiotherapy positioning devices, if necessary, and to apply accurately the angiographic catheter (7F) on the patient's skin to indicate fiducial reference points and field outlines, if optimum benefit from the treatment planning were to be obtained. The body contour was outlined automatically from the scan and displayed on the monitor. Tumors were outlined on all relevant sections. From the planning CT information, pattern of local extent of tumor and the relations between the tumor and the uninvolved normal tissues were also reassessed. Computation of dose and graphic of isodose curve were done directly on the images of the scan. 3-Dimensional (coronal, axial, sagittal) analysis of dose distribution could yield good information. Then the patient's problems and treatment goals were reviewed again and the treatment plans were revised, if necessary. This procedure is schematically illustrated in Table 2.

RESULTS

In 10 (23.8%) of the 42 patients some readjustments in radiotherapy technique were made as a result of planning CT scan (Table 3). In 2 patients changes in the treatment field numbers or angulation of fields were made. In one, nodal metastasis

Table 1. Patient Distribution by Anatomic Grouping

Primary site	No. of pts.	Histology	No. of pts.
Nasal cavity	5	Malignant midline reticulosis	3
		Lymphoepithelioma	2
Oral cavity	4	Malignant midline reticulosis	1
		Squamous cell carcinoma	3
Nasopharynx	5	Malignant midline reticulosis	1
		Lymphoepithelioma	2
		Undifferentiated carcinoma	2
Oropharynx	9	Non-Hodgkin's lymphoma, PDL*	6
		Squamous cell carcinoma	2
		Undifferentiated carcinoma	1
Larynx			
Supraglottic	1	Squamous cell carcinoma	1
Glottic	4	Squamous cell carcinoma	4
Hypopharynx	2	Squamous cell carcinoma	1
		Small cell carcinoma	1
Maxilla	5	Squamous cell carcinoma	3
		Pleomorphic adenoma	1
		Non-Hodgkin's lymphoma, PDL *	1
Parotid gland	2	Adenoid cystic carcinoma	1
		Mucoepidermoid carcinoma	1
Trachea	1	Squamous cell carcinoma	1
Orbit	3	Retinoblastoma	2
		Adenoid cystic carcinoma	1
External ear	1	Squamous cell carcinoma	1
Total	42		42

* Poorly differentiated lymphocytic lymphoma

was identified from the original site of maxillary antrum by planning CT scan and neck nodal treatment was initiated together. Complete local control was reported at the end of treatment. The other patient had recurrent squamous cell carcinoma of external auditary canal after 5 months of subtotal resection of temporal bone. There showed significant modifications in tissue planes after surgery. Important organs around the temporal bone and contained hearing and equilibrium organs were identified with superimposed isodose curve on the image through dose computation. The patient was treated with paired wedge technique to the curative dose without hampering the status of surrounding tissues. In the remaining 8 patients, the alterations consisted of the modification of radiotherapeutic field size or shape, or change in the location of shielding areas because of changed volume of irradiation. These changes in treatment planning were based on the information from 3-D reconstruction, that is, axial, coronal, and sagittal plane.

The followings are brief reports of two patients especially benefited from planning CT scanning.

Patient 1; This 49-year-old woman was presented with undifferentiated carcinoma of the nasopharynx, stage III (T3NIMO). She was treated with two cycles of induction cyclophosphamide, vincristine, bleomycin chemotherapy without apparent response followed by 7000 cGy of radiotherapy with curative intent and with usual nasopharyngeal treatment ports. At this time no planning CT was done. The tumor disappeared completely at the end of treatment. But 1 month after treatment, there was noted mulberry type hypertrophic mass in her right nasal cavity. Pathology revealed recurrent undifferentiated carcinoma. Then we decided planning CT scan, and dose computation was done. 3-D reconstruction image showed good dosimetry as in Figure 1. The tumoricidal isodose curve surrounded the tumor mass adequately but sparing the previously irradiated nasopharyngeal area within its acceptable dose. 6000 cGy of radiation was delivered on her nasal cavity to identify complete local control. There was no evidence of recurrence at 4 months' follow-up examination.

Patient 2; This 38-year-old man experienced hemoptysis on January 10, 1986. He visited the otolaryngologic clinic of our hospital. Diagnosis was tracheal cancer. The otolaryngologist recommended radiotherapy, but he received only 800 cGy to his neck and refused treatment. On April 30, 1986 sudden dyspnea developed with productive coughing. He came to emergency room and bronchoscopy was done. There showed near-total obstruction of trachea just below the vocal cord. He gasped on Cheyne-stokes respiration. Intubation failed. Emergency tracheostomy was done. The tracheal lumen was filled with tumor mass and the tracheostomy tube was inserted through the tumor. Biopsy revealed squamous cell carcinoma. Neck CT showed the tumor mass just below the vocal cord extending to the level 0.5 cm above the carina. Vocal cord and carina were normal and there was no nodal involvement. He was irradiated 6000 cGy in midplane with anterior, posteior, and both lateral ports (after 4500 cGy). The tumor clearly disappeared. On September 16, 1986, he experienced dyspnea and tracheal stricutre was noted. Permanent trachesotomy was done. He was well thereafter. But on June 18, 1987, he experi-

Table 2. Method of Radiotherapy Planning CT

Decide treatment options
↓
External beams → No → Other types of treatment
↓
Simulation and field radiograph
↓
Prescription and doses
↓
Planning CT with treatment position
↓
Dose computation and verification
↓
Accepted dosimetry → No → Consider other dosimetry
↓
Treatment with immobilization

Enlargement of the image in the actual size was not necessary by using the CT image in superposition with isodose curve.

Table 3. Changes in Treatment as a Result of Planning CT

Primary site	No. of pts changed /No. in group	% pts with change	No. pts no. or angulation of fields	No. pts Change in field shape or size
Nasal cavity	1/5	20%		1
Oral cavity	1/4	25%		1
Nasopharynx	1/5	20%		1
Oropharynx	3/9	33%		3
Larynx, glottic	1/4	25%		1
Maxilla	2/5	40%	1	1
External ear	1/1		1	
Total (% of 42 pts)	10/42	23.8%	2	8

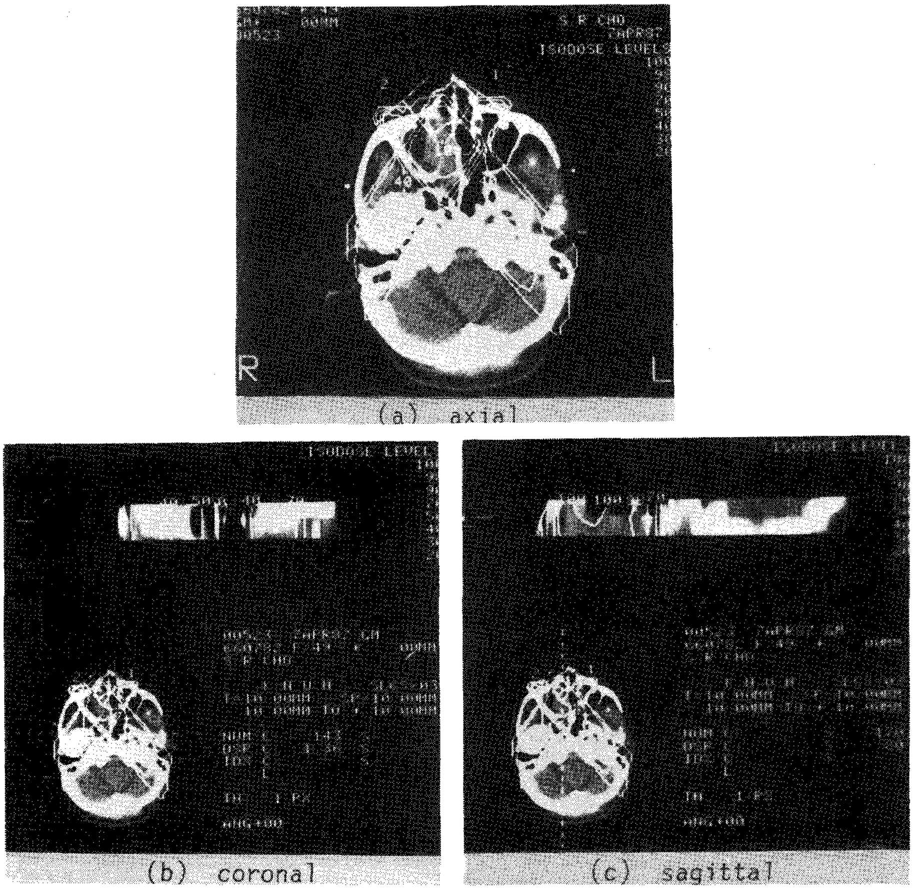

Fig. 1. Reconstructed CT image of patient 1, with isodose curve superimposed. Isodose curve surrounded the tumor mass adequately sparing the previously irradiated nasopharyngeal area.

enced hemoptysis again and tracheal punch biopsy was done. Pathology revealed recurrent squamous cell carcinoma. Bronchoscopy and neck CT showed regrowing mass along tracheal mucosa about 3 cm in length from the stoma inferiorly. One cycle of induction cyclophosphamide, vincristine, bleomycin chemotherapy was done and radiotherapy was planned. But because the trachea was located just anterior to the spine which was curved and the spinal cord received 4500 cGy already from previous treatment, we have done planning CT scan and dose computation. Sagittal reconstruction of the spinal cord together with isodose curve showed relevant dose distribution of acceptable range on whole length of the spinal cord included in the field. So the patient was treated 2000 cGy with oblique beam direction to avoid spinal cord damage as shown in figure 2, and intracavitary radiation as booster treatment and/or hyperthermia was planned.

DISCUSSION

Many investigators reported that the radiation treatment planning CT was of great advantage for the treatment of cancers of the thorax, abdomen, pelvis and extremities[1~5]. However, reports regarding to the head and neck region were relatively scanty[5].

Munzenrider et al.[3] reported in their 9 head and neck cancer patients that planning CT was not so advantageous in determining the changes in the dose of radiation into adjacent normal tissues. Because, in most of the head and neck cancer patients, physical examination and conventional radiography were not sufficient to identify accurately the site and extent of cancer, diagnostic CT was done to know the exact location and depth of

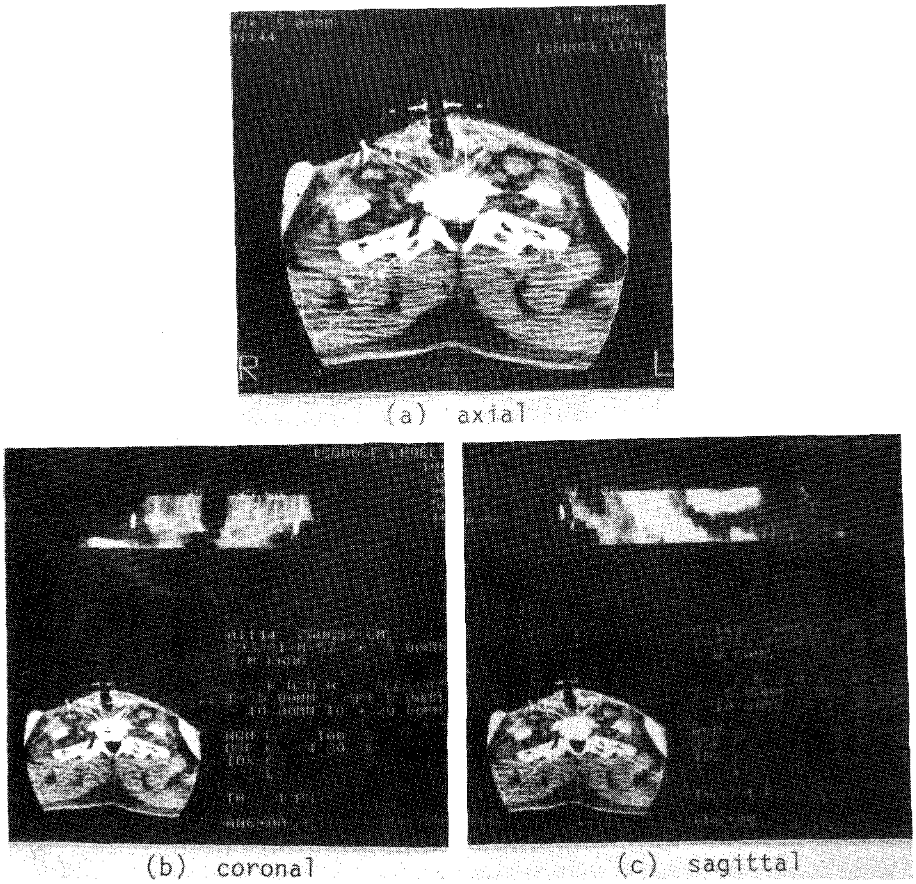

Fig. 2. CT reconstruction of patient 2. Tumor mass was not seen on the images. But the tumor was spreading along the tracheal mucosa. Relevant isodose distribution on whole length of the spinal cord was shown on the sagittal section.

infiltration of tumor and to make the therapeutic device before the radiation treatment was begun. So planning CT was usually omitted.

Hobday et al.[5] assessed the role of CT in radiation therapy planning. They have done planning CT in 123 patients. Of them, only 9 cases of head and neck cancer patients with nasopharynx, maxillary antrum, and obital tumors were studied. There were 3 cases of inadequate tumor coverage identified by planning CT. But such a number was too small to say whether this figure is representative of the whole group. Our result of changes in the treatment technique after planning CT, 23.8%, was roughly similar to Hobday's report[5]. But on account of the rarity of reports about the value of planning CT, the comparison is somewhat unreasonable. Anyway, the patients who were treated just as the result of planning CT showed complete local control according to the author.

Complete local control of tumors ensures longer survival[7]. It is also applied to head and neck cancer patients. Accurate tumor detection, staging, and selection of treatment goals and modalities by planning CT prior to the entry into radiation therapy would provide the capability for systematic improvement in optimal dose distribution which is accurately computed and corrected for the individual's heterogeneous·tissues by 3-D reconstruction analysis as shown in our cases. CT scan data permit more accurate and composite calculation of the delivered radiation dose. Thus marginal miss would be reduced and excellent local control could be achieved. Cho et al.[8] studied about the efficacy of CT-aided radiotherapy planning in 15 head and neck cancer patients. They concluded that marginal miss was reduced and local control was maximized with planning CT. Reduction of marginal miss by planning CT was also witnessed by Goitein et al.[9] in their prospective study on the value of CT scanning in radiotherapy planning.

Stewart, et al.[10] insisted that following minimal criteria should be met for the CT scanner to be a therapy planner. a) Hounsefield number of water and air should be reproducible with +/− 2%, b) Hounsefield number versus electron density should be linear within +/− 2% in the range of water-to-air, and c) less than +/− 2% variation of Hounsefield numbers across 90% of a 30 cm diameter water flood scan. GE CT/T8800 at our institution met the above criteria enough to be a radiotherapeutic planner. In addition, the accurate position information obtainable from CT scans was transferable to the therapy unit by using the same positioning devices. Reconstructed data was also available in numerical format and was readily transferable to dose calculation computer. Especially multiple scans of a patient can be made to derive 3-D information. Reconstruction of these scans in a sagittal or coronal plane was a desirable feature as well as the simulation of a portal view.

Treatment planning systems in common use generate 2-D distributions which incorporate simple corrections for tissue heterogeneities based on an effective depth method of similar approach[11,12]. However, the most accurate approach is to take into account the effect of scattered radiation from other tissues irrespective of the plane of calculation. This complex method was developed by Sidwell and Burlin using Monte Carlo method to estimate dose distributions in the thorax[13], and thereafter modified a little by other investigators[14~16]. Battista, et al.[17] assessed the value of CT-derived treatment plans for dose distributions. The effects of tissue inhomogeneities have been most pronounced in the thorax where lung and air cavities can significantly alter the dose distributions. The example of cancer of the upper esophagus in their study illustrated the usefulness of CT in tissue localization and in dose calculations where the effect of tissue inhomogeneities is taken into account. Hence more accurate dose distributions can be produced in which the dose to the tumor and to the surrounding healthy tissue (eg, spinal cord) can be predicted as in our case of patient 2.

3-D representation of isodose distributions has been developed[6,12,16,18], which involves establishing a patient structure data base, positioning the beams of radiation, characterizing the plans of calculation, etc. Though Sterling et al.[19] have made movie films which show the change of dose distribution through different patient slices, it was not so practical. The utilization of the imaging system of the CT scanner has made it possible to provide an effective illustration to display in superposition the gray-scale patient structure image, the radiation beams and the isodose distributions as multiple frames. Moreover, such a method of CT-based radiation therapy treatment planning made it possible to evaluate numerous off-axis images. Now, the accuracy of off-axis calculations has become a more practical concern[16,18].

As mentioned earlier, tumors are 3-D structures. Many tumors have a relatively uniform shape when imaged on widely spaced transverse sections and fit within standard treatment fields. However, some tumors could appear to be wide only on a single transverse section. Though Lichter[6] suggested that fully 3-D display of integrated and stacked CT images provided visualization of the true extent of the tumor in relation to normal tissues in a single display, when noncoplanar beams enter from unusual oblique angles it becomes very difficult to image the tumor accurately on simulator. And the integrated method is still not so practical to apply routinely to the patients. Our study using radiotherapy planning CT scanner revealed precise tumor localization and extent, isodose calculation and distribution which is able to applicate to the patients easily and practically, by 3-D reconstruction images (axial, coronal, and sagittal) though it was not an integrated and stacked display.

CONCLUSION

There are clinical situations in which lack of adequate dose to the margin of a tumor results in tumor recurrence. The ability to plan treatment in increased precision would allow an increased dose to the periphery of the tumor, raising the local control with significant gains in eradicating disease by reduction in the chance of geographic miss especially in head and neck cancers. The three-dimensional reconstruction CT scans (axial, coronal, and sagittal) in radiation therapy treatment planning was practical and accurate in identifying exact tumor volume and dose distribution, while unnecessary administration of radiation to normal tissues could be avoided when delivering high dose to the tumor. In addition, it was more informative than traditional two-dimensional radiotherapy planning.

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═ 국문초록 ═

CT 재구성에 의한 두경부 종양의 방사선 치료 계획

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방사선 치료의 궁극적인 목적은 정상 조직의 후유증을 최소화하면서 암종의 완전 국소 관해를 도모하는데 있다. 1970년대에 전산화 단층 촬영법이 대두된 후로 환자의 해부학적 정상 조직과 암종의 부위와 침윤 정도를 거의 정확하게 알게 되었고, 표적 암조직에 인체 외부에서 가해지는 방사선의 등선량 곡선을 각 단면에서 확인할 수 있었다. 특히 두경부 종양의 방사선 치료 계획에 있어서 재구성 영상으로 암종과 주위 정상 조직의 상관관계를 삼차원적으로 파악하고 영상 위에서 바로 등선량 곡선을 볼 수 있으므로 암종에는 관해에 충분한 방사선을 투여하면서 정상 조직(예, 척수 등)에 가해지는 방사선량을 명확히 알 수 있어 최소한의 선량으로 후유증을 방지할 수 있었다. 이는 축, 종, 횡, 단면의 재구성 영상을 얻어서 이루어질 수 있고 종래의 이차원적인 한 개의 단면에서만 시행하던 치료 계획을 서로 다른 세 개의 단면에서 삼차원적으로 시행함으로서 입체적으로 분포 선량을 추정할 수 있어 두경부 종양 환자의 치료에 더 유익하였다.