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# Design and Dose Distribution of Docking Applicator for an Intraoperative Radiation Therapy

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**A docking intraoperative electron beam applicator system, which is easily docking in the collimator for a linear accelerator after setting a sterilized transparent cone on the tumor bearing area in the operation room, has been designed to optimize dose distribution and to improve the efficiency of radiation treatment method with linear accelerator.**

**This applicator system consisted of collimator holder with shielded metals and docking cone with transparent acrylic cylinder.**

**A number of technical innovations have been used in the design of this system, this dooking cone gives a improving latral dose coverage at therapeutic volume.**

**The position of 90% isodose curve under surface of 8 cm diameter cone was extended 4~7 mm at 12 MeV electron and the isodose measurements beneath the cone wall showed hot spots as great as 106% for acrylic cone. The leakage radiation dose to tissues outside the cone wall was reduced as 3~5% of output dose. A comprehensive set of dosimetric characteristics of the intraoperative radiation therapy applicator system is presented.**

**Key Words:** Intraoperative radiation therapy, Docking applicator, Pentagonal cone, Electron dosimetry

## INTRODUCTION

Intraoperative radiation therapy (IORT) is a multidisciplinary procedure which combines two conventional methods of cancer treatment, namely, surgery and radiation therapy. The purpose is to deliver a large single dose of radiation to the tumor or tumor bed, while minimizing to a much higher degree the dose to normal structures[1].

IORT may improve the therapeutic ration of tumor control to normal tissue injury both by direct visualization of the tumor volume and direct appositional treatment which permits exclusion of all or part of a sensitive normal tissue or organ by operative mobilization, customized lead shielding and the selection of appropriate beam energies. Theoretically, these are major advantages when compared to the conventional use of external beam irradiation.

Yonsei cancer center initiated a pilot study of multidisciplinary IORT program in February of 1986 for the first atempt in Korea[2].

IORT was performed in 10 patients with stomach cancer by using existing NEC 18 MeV Linear Accelerator treatment room as a surgical suite (Fig. 1).

To proceeding IORT, many special teams including the department of surgery, department of anesthesiology, department of clinical pathology, operating room nursing personnel and department of radiation oncology have to co-operate to be achieve better results.

Also there are many problems that have to provided all surgical equipments for operation and have been sterilized inside of linear accelerator room and have to stop the treatment of radiation to the other patients. By these reasons, we want to design and fabrication of docking applicator, After being operated, the patients setting with docking cone were moved to LINAC room and irradiated after docking the cone into the collimator holder attached to the head of the accelerator.

IORT applicator systems require a physical docking between the linear accelerator collimator head and a patient fixed cone which defines the treatment volume.

As a consequence, the joining of the cone to the accelerator, or docking, represents a difficult mechanical alignment procedure in three dimensions between the accelerator and the patient support assembly, either an accelerator couch or an operating room table. In addition, the target volume is often impossible to view during and after

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**Fig. 1.** Intraoperative electron irradiation to carcinoma of the stomach with an IORT applicator.

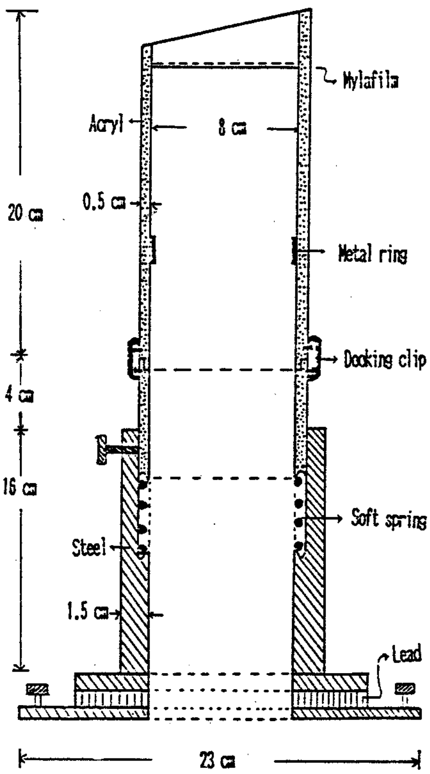


**Fig. 2.** Schematic diagram of IORT docking applicator.

this docking[3], and the soft docking system was developed to provide the visualization problems without sacrificing accelerator patient cone alignment precision. This is accomplished physical docking between the treatment volume and the accelerator, using clear plexiglass and mylafilm under clinically acceptable.

## METHODS AND MATERIALS

We designed and fabricated the docking applicator system for IORT, which consist of an electron collimator holder to be attached to the accelerator head as a standard size electron cone and the soft docking cone with a circular, pentagonal shape, or other regularly shaped cross-section through which the electrons pass in route to irradiating the target volume in the patients[4].

A technique has been employed to irradiate the tumor bearing area using a sterilized acrylic cone by sliding into a metal collimator holder attached to the head of the accelerator[5,6]. The acrylic docking cone is inserted into the patient directly over the tumor, the patient couch is adjusted until the cone is correctly aligned inside the holder.

The wall of the cone shields the patient anatomy outside the cone from primary radiation[7]. The homogeneity of dose to the patient's target volume and the leakage dose outside the cone depend on the cone design and how it is interfaced to the therapy machine[8].

The collimator holder and docking cone should allow only minimal leakage to the patient and should be easily sterilizable, the docking cone should be as light as possible and needed long length to reach tumors deep within the abdomen.

The resulting dose distribution within the patient should be as uniform as possible inside the 90% isodose surface and the geometric coverage of the 90% isodose surface should be as large as possible.

We discuss a number of design techniques, including determination of the thickness of circular trimmers and the wall thickness of cones and evaluation of internal blocking ring geometry.

Fig. 2, 3 illustrates the IORT applicator system consist of a collimator holder to be complete attached to the LINAC collimator and soft docking cone to be composed light transparent acrylic wall and thin mylafilm to protect from out air for moving from operation room to linear accelerator facility.

In determining the size and shape of the collimator holder and docking cone, two types of electron leakage were considered, the transmission of electrons through the holder material and the scattering of electrons outside the outer edge of its high density, durability, machinability and medium atomic number. It was felt that excessive bremsstrahlung production in a higher Z material would exacerbate room x-ray leakage. On the other hand the low density of lower Z materials would require substantially thicker collimating annuli, perhaps leading to needless electron leakage from scatter off the cone walls.

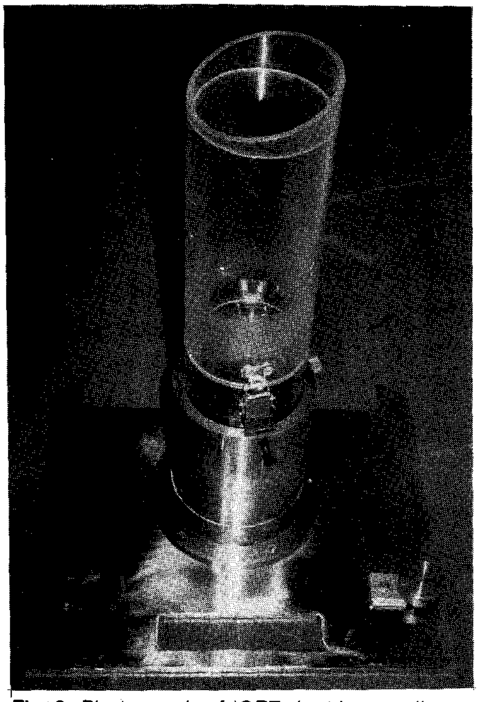

**Fig. 3.** Photograph of IORT docking applicator.

The docking cone with acrylic offers the advantage of being transparent and has been frequently used for intraoperative electron therapy. As a minimum, the cone wall thickness should be such that the thickness along a diagonal ray from the source is at least the maximum range ($R_{max}$) of a broad electron beam. The maximum diagonal thickness occurs for the largest field diameter and that portion of the cone closest to the source. When the source to surface distance is 100 cm, a 8 cm diameter, 30 cm long cone has a maximum diagonal wall thickness given by

$$t_{wall} = R_{max} \cdot \sin \theta_{max} = 0.08\, R_{max} \quad (1)$$

Hence a wall thickness of approximately 5 mm at 12 MeV for acrylic is required. The size and location of the collimating annuli were determined using the clinical constraints described earlier and the theory of electron transport through air. As electrons pass through air they undergo multiple Coulomb scattering, which results in a lateral spreading of the electron beam. Lateral electron distributions in air can be calculated using Fermi Eyges multiple scattering theory[9].

The lateral dimensions of the collimator holder annuli were selected to minimize weight and leakage. The penumbra generated by an upstream collimator must be shielded by a downstream cone wall. For a collimator edge perpendicular to the central axis, the inner edge should lie 1.5 times $\delta_x$ inside the projected edge to ensure uniformity of electron fluence within the aperture.

$\delta_x$ is the root mean square value of the lateral spatial distribution of an electron pencil beam originating at the upstream collimator and arriving at the downstream cone wall. It is derived from fundamental pencil beam equations[9,10] resulting in

$$\delta^2_x = \left(\frac{d\delta^2}{ds}\right)^{Ep.o}_{air} (S_l - S_{l-1})^2 \cdot S_l/6 \quad (2)$$

Where $S_l$ is the distance from the electron source to the bottom of the applicator holder wall and $S_{l-1}$ is the distance from the source to the bottom of the cone wall. The linear angular scattering power in air for the most probable incident energy, $E_{p.o}$, equaling 6 MeV is approximated by[11]

$$\left(\frac{d\delta^2}{ds}\right)^{6MeV}_{air.STP} = 2.3 \times 10^{-4}\ \text{radian}^2/\text{cm} \quad (3)$$

For calculation purposes, 6 MeV was selected because electrons scatter the most at the lowest energy. Our design theory applies to circular fields, it results in an upper limit for leakage. Fig. 4, 5 illustrates the schematic diagram of pentagonal cone for coverage of celiac axis lymph node groups after gastrectomy with optimum dose distribution.

The dose measurements were made using the 7, 8 cm diameter cylindrical docking cones and 6, 7 cm pentagonal cones at energies of 6, 9, 12 MeV with the NEC Linear Accelerator in Yonsei Cancer Center.

Standard dosimetric quantities in intraoperative electron beam radiation therapy are of interest for beam uniformity, surface dose, therapeutic depth dose, bremsstrahlung and cone leakage radiation to the surrounding tissues.

The dosimetry data have been obtained from measurements in water using a 3 dimensional beam scanner (Fujitec-FM0036). Tow solid detectors, one as a reference detector and the other as scanning detector, were used in the depth dose and cross beam profile measurements. The isodose distributions were generated from the measured two dimensional scanning. Treatment cone leakage measurements were made both in water and air, perpendicular to the 8 cm diameter cone for 12 MeV electron beam. All leakage measurement data were normalized to the maximum dose on the central axis in water. The output dose measurements were made in a lucite phantom using a parallel plate chamber (Capintec PR05).

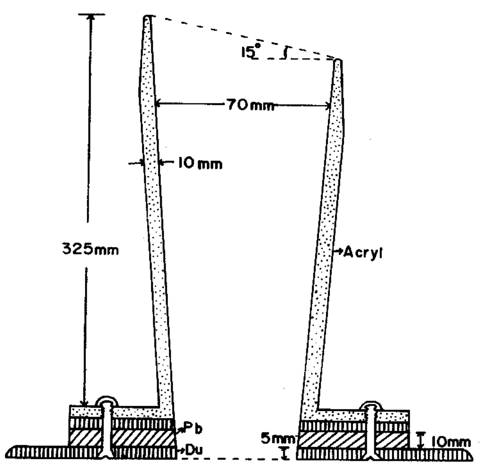

Fig. 4. Schematic diagram of Pentagonal applicator for IORT.

The chamber was positioned within a 30 cm×30 cm lucite slab so that the entrance window was flush with the lucite phantom surface. Measurements were made with both positive and negative polarity and the average value of these readings was taken for relative dose calculations.

## RESULTS

### 1. Dose Distribution

The design of an applicator system influences the shape of isodose curves, Fig. 6 is shown the isodose curve for a circular docking cone of 8 cm diameter at 12 MeV electron beam, there are high dose areas laterally at shallow depths.

The increased fluence of electrons at the periphery of the cone produces much flatter isodose curves, thus improving lateral coverage at therapeutic depths about 0.5 cm of the 90% isodose curve, but it is always associated with high dose

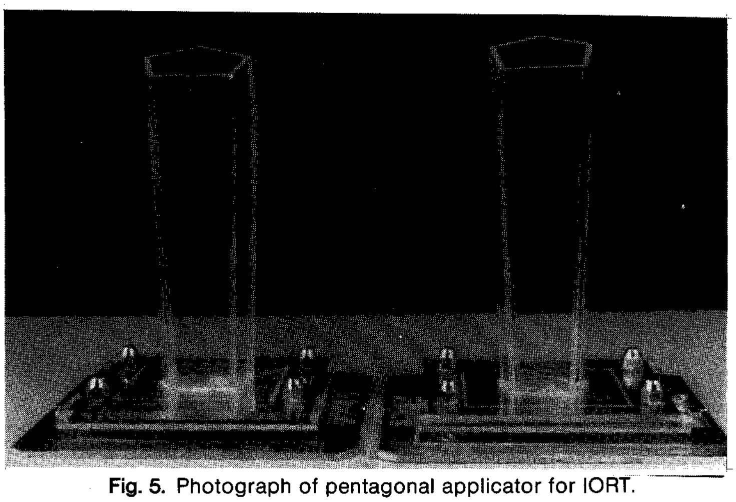
Fig. 5. Photograph of pentagonal applicator for IORT.

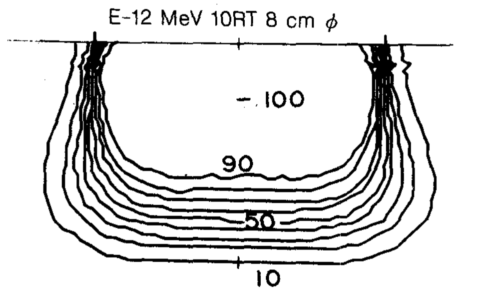


**Fig. 6.** Isodose curve of electron beam by docking applicator.

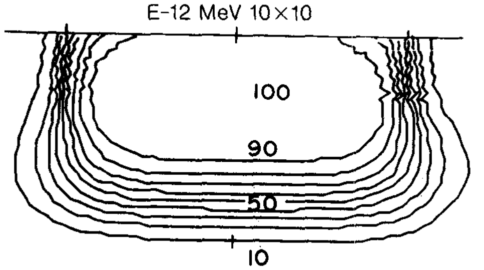


**Fig. 7.** Isodose curve of electron beam by standard rectangular cone.

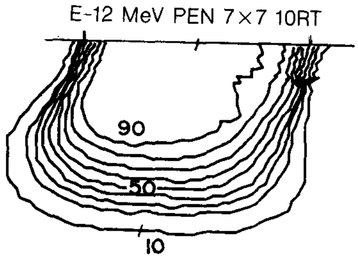


**Fig. 8.** Isodose curve of electron beam by pentagonal applicator.

areas at the periphery. The magnitude of the high dose at the periphery can be as high as 6% for 12 MeV electron beams of 10×10 cm normal field size cone (Fig. 7). The lateral coverage of isodose lines in both cases is very similar, but the lateral coverage with IORT cone with the usual rounding of the isodose curves at the periphery. However, if a clinical situation warrants on decreased lateral coverage, the steel ring can be attached inside wall of cone. Fig. 8 illustrates the isodose curve of the bevel plane by IORT pentagonal cone with high dose level on the central area then periphery of the cone without attaching metal tape.

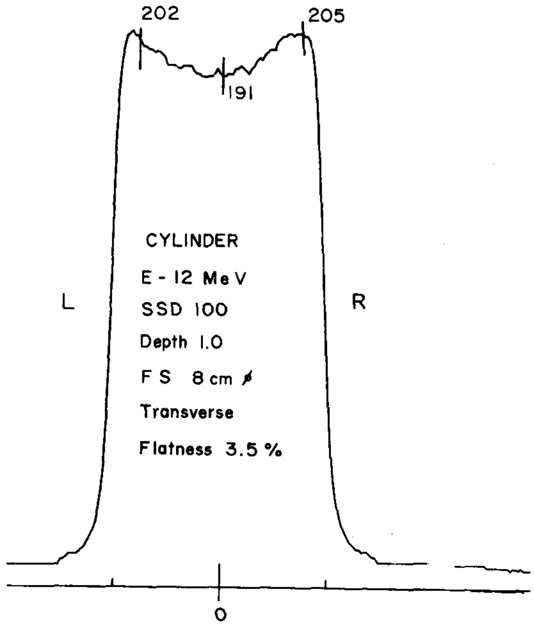


**Fig. 9.** Dose flatness of electron beam at 1 cm under water surface by docking applicator.

## 2. Beam Flatness

Measurements of beam profiles for IORT docking cones have shown areas of increased dose just inside the edges of the cone. This is caused by the streaming of scattered electrons from the lucite wall[12]. The magnitude of this high dose region is independent of the photon jaws opening as long as the incident electron fluence profile on top of the applicator does not change. It has been suggested that the high dose areas can be reduced by optimizing the photon jaws opening to adjust the electron fluence striking the walls of the cone and adding a small metallic ring on the inside of the cone to intercept the streaming electrons. In the present cone design, a steel ring which is 15 mm wide in the beam direction and has a radial thickness of 1 mm is used. The advantage of a steel ring is that it diffuses the streaming electrons through large angles thus giving a very uniform and flat beam profile. Various positions of the steel ring along the beam axis were experimented. For this cone design, positioning the ring in the middle of the cone was optimal for all energies Fig. 9 illustrates the beam flatness of docking applicator without the addition of the steel ring for 12 MeV electron beam. The addition of the ring removes the high dose

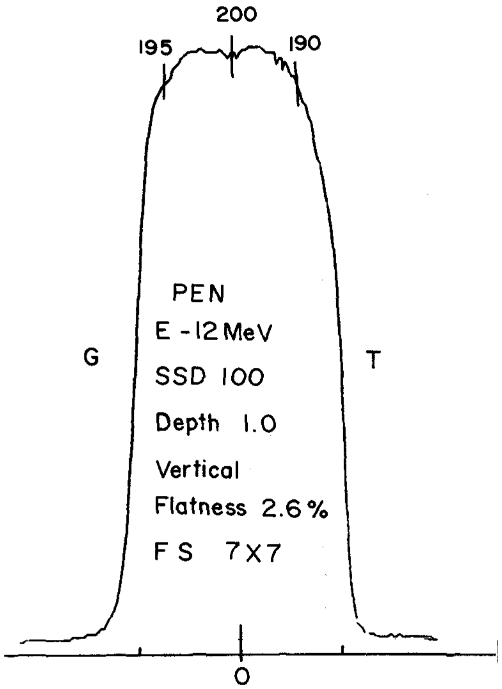


**Fig. 10.** Dose flatness of electron beam at 1 cm under water surface by pentagonal applicator.

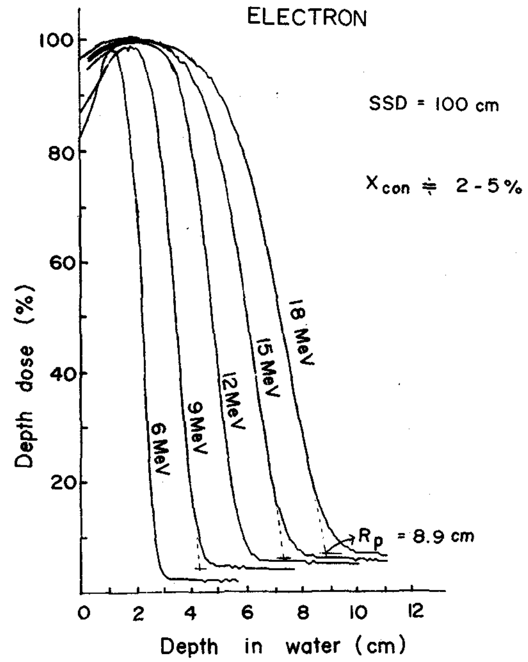


**Fig. 11.** Percentage depth dose for 6-18 MeV electron beam for 8 cm diameter IORT docking applicator.

areas without compromising the beam flatness at field edges for all energies of electron beams. Fig. 10 shows the beam profile of the pantagonal cone of 7 cm diameter for 12 MeV electron beam, the high dose of the beam profile distribute on the center area of the cone because of the scattering of collimator metallic holder.

### 3. Depth Dose

The depth doses were calculated from the measured along the central axis of cones for all electron energies. The data for the beveled edges were measured perpendicular to the water surface and in the center of the field. The end of the cone was flush with the water surface at nominal 100 cm SSD. The gantry was rotated such that the central axis of the beam was coincident with the central axis of the cone. Depth doses are normalized to the maximum dose on the measurement axis. The results of the measured data are shown in Fig. 11. The central axis depth dose data for the IORT applicator is almost identical to the data for the manufacturer supplied treatment applicators with inserts of same field size.

The central axis depth dose change significantly for small cone size and energies greater than 15 MeV. The depth dose coverage with bevel ended cones is less than that with flat ended cones. The measured surface doses increase from 85~96% with increase in electron energy from 6~18 MeV. The surface dose does not change significantly with the bevel end[13].

### 4. Cone Leakage

The dose outside the acrylic docking cone is clinically important in intraoperative radiation therapy because a large dose is delivered to the tumor in single fraction. It is not only important to determine leakage dose at the end of the cones but also along the wall of the cones. Invariably, normal tissues extend up to some height along the walls of the cone. The leakage radiation in the region surrounding the bottom half of the cone is less than 3%, but can be as high as 5% in regions close to the wall at the upper part of the cone. The radiation leakage through the stainless steel holder, which is primarily due to bremmsstrahlung photons, is always less than 3% for all cones. much effort is taken to retract normal tissues away from the acrylic cone to decrease the radiation dose to the normal tissue.

## DISCUSSION

Intraoperative radiation therapy is a cancer treatment modality in which resectable masses or organs are removed surgically and residual cancer cells are sterilized by irradiation with a single massive dose during operation while patient is still anesthesized.

Because it is possible that the tumor mass can be visualized directly at the time of surgical exploration, tumor volume can be determined more precisely and at the same time sensitive adjacent structures can be pulled aside from the irradiation. With these theoretical advantages as compare to conventional external irradiation, IORT can improve the therapeutic ratio of tumor control to normal tissue injury.

Yonsei Cancer center has performed the multidisciplinary IORT since 1986 in 10 patients with stomach cancer by using existing NEC 18 MeV linear accelerator treatment room as a surgical suite[2].

To proceeding IORT, there are many problems that the LINAC room have to provided to be acted as a operation room with all surgical equipments and have been sterilized by UV lamps and radiation patients for LINAC could not be treated during one or two days for only one IORT patient and we designed docking applicators to be saperating procedure. A sterilized acrylic cone fixed on the tumor bearing in the operating room and docked into the collimator holder attached to the head of the accelerator after transfer to the LINAC room.

Though the concept of intraoperative radiation therapy is relatively simple, the technical complexity of this procedure requires a careful evaluation and appropriate modification of the conventional dosimetric methods used in electron beam therapy. A special cone arrangement is needed to direct radiation into the surgical opening that exposes the tumor or tumor bed. The cone serves the primary purpose of collimation of the electron beam and additionally directs the beam to a well defined target. Some times, it also helps in retracting normal tissues away from the treatment field.

The dosimetric characteristics of an IORT applicator system depend largely on the characteristics of the electron beams generated in the treatment head of a particular linear accelerator. Therefore, similar applicator systems used with different accelerators will have different beam characteristics. The design, shape and size of each intraoperative cone affects the dosimetric characteristics for the depth dose, surface dose, flatness, x-ray contamination, dose output rate and leakage radiation through the cone walls.

The IORT docking cone designed for use at Yonsei Cancer Center provided optimal beam characteristics with our linear accelerators. The set up of the patient for treatment is precise and quick with this docking cone and high dose areas in the periphery of the fields are removed using a steel ring without conpromising the lateral coverage. The constriction of higher isodose curves as compared to the comventional electron field is similar. The design of the collimator system for the intraoperative cones is such that applicators of different cross sectional shapes, namely, circles and pentagonal shape can be conveniently constructed with optimized beam characteristics.

The intraoperative radiation therapy team of radiation oncologists, physicists, surgeons, anesthesiologists and nursing staff has expressed satisfaction with the whole procedure. Further work is continuing to design applcators with different cross sectional shapes for various clinical sites.

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＝국문초록＝

## 수술중 방사선치료를 위한 조립형 조사기구의 제작과 선량 분포

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수술중 방사선치료법(Intraoperative Radiation Therapy)은 외과적으로 개복된 상태에서 종양이나 장기를 절제한후 비가시적 또는 육안적 암세포를 전자선등으로 직접 조사 치료하는 방법으로서 일시에 다량의 방사선량을 종양부위에 집중적으로 조사할 수 있으며 정상장기나 조직을 방사선 조사 범위로부터 차단함으로 방사선 손상을 격감 시킬 수 있는 장점을 갖고 있다.

본 연세암쎈터 치료방사선과에서는 1986년 2월부터 현재까지 십여명의 위암환자를 대상으로 수술중 방사선치료를 시행하여 좋은 결과를 얻었으나 치료절차상 많은 어려운점이 야기되어왔다.

그중에서도 방사선치료실(LINAC room)내에서 수술을 시행함에 따른 수술기구, 응급처치 장치, 조명 및 감시장치 등이 완벽하게 준비되여져야 하며 치료실내를 2~3일 동안 자외선과 소독약으로 완전히 제독 하여야 함으로 그기간 동안 많은 방사선치료 환자들이 한명의 IORT 환자를 위하여 치료를 중단하여야 하는 어려움이 있었다.

본 연세 암쎈터에서는 콜리메터 접속기구(collimator holder)와 투명 조사통(Acrylic cone)으로 구성된 조립형 조사기구(Docking Applicator)를 고안 제작하여 수술과 방사선 치료를 각각 해당 장소에서 시행할 수 있었다. 즉 IORT 환자의 개복수술은 수술실에서 시행하되 다만 가볍고 투명하며 외부 공기와 차단된 투명 조사기구(Acrylic cone)를 종양 부위에 조준고정 시켜 봉합하고 방사선 치료실로 이송된후 선형가속기의 방사구에 장착된 콜리메터 접속기와 접합 시킴으로서 많은 문제점을 해결할 수 있었다.

조립조사 기구는 치료부위를 잘 관찰할 수 있고 쉽게 결합할 수 있도록 가벼운 아크릴과 Mylafilm으로 구성 제작하였으며 콜리메터 접속기는 종양 부위에 균일한 선량분포와 누출선량을 줄이기 위하여 스텐레스 강철로 구성제작하였다.

직경이 8 cm이고 길이가 30 cm인 접합형 조사기구를 사용하여 12 MeV 전자선을 조사하였을때 90%의 등선량곡선이 5 mm 정도 확장 되었으며 조사통 가장자리의 선량이 약 6% 증가하였다. 조사통밖 의 누출 선량은 위치에 따라 출력선량의 3~5%가 측정되었고 심부 백분율은 기준조사통에 의한 것과 유사하였다. 조사통의 모양과 크기는 종양범위에 알맞도록 원형, 사각형 또는 오각형 등으로 제작하였으며 1~2 cm의 금속띠를 이용 조절하므로서 최적한 선량분포를 얻을수 있었고 콜리메터의 차폐 금속편을 이용하여 조사통밖의 누출선량을 최대한으로 줄일 수 있었다.