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COMPUTERIZED TREATMENT PLANNING AND INHOMOGENEITIES

by

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Historically speaking the interest of the physicist and radiation therapist in inhomogeneities and the possible effects that they do or do not have in the patient undergoing radiation therapy is not new. As early as 1920 FAILLA investigated the absorption of gamma rays from a radium source by various tissues. This experiment consisted of using various slices and thicknesses of different tissues as absorbers. The resultant transmission measurements were taken with an electroscope.

One of the first measurements that was taken in cadavers was in 1923 by BORELL in Germany. However, in 1934 QUIMBY reported that there was some concern as to whether the previous measurements were actually representative of the true distributions within the patient. In view of this QUIMBY et coll. did an experiment using a male cadaver fixed in phenol and glycerine. Unfortunately, in today's society, it is doubtful whether we would be able to conduct these experiments again. Hence we find ourselves forty years later, still trying to approach this problem on a routine basis.

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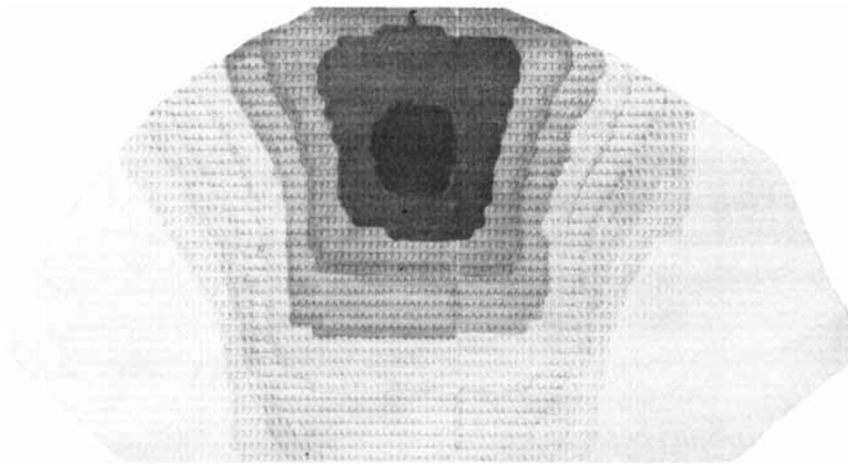

Fig. 1. ^{60}Co treatment plan of urinary bladder using a field size of 13 cm × 10 cm and 90° anterior oscillation and the axis located posteriorly. The dose to the bladder area is very intense with a sharp fall off outside the area.

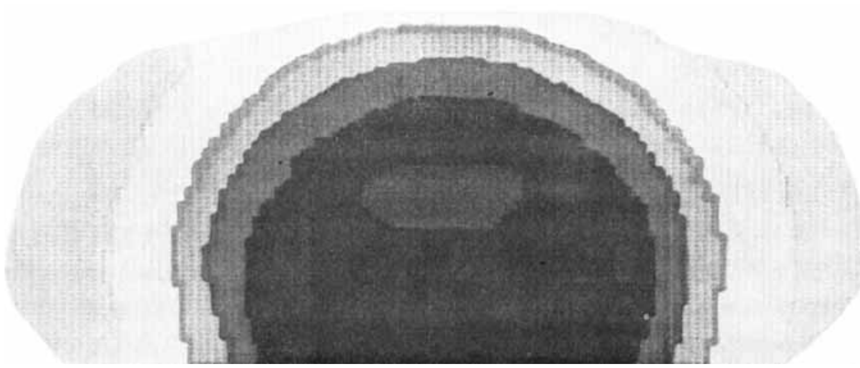

Fig. 2. Dose distribution for unit density calculation of squamous cell carcinoma of the cervix. Field size 18 cm × 20 cm and 360° rotation. T/A 0.70.

Today, the problem is being approached in a different manner by using predominantly mathematical models. However, we still find ourselves going back to the human body to corroborate our results by inserting ionization chambers into various orifices in the body to check the calculations that are made on the patient either manually or with computers. We still find many members who are startled by the dose distributions obtained when all the inhomogeneities that are encountered when the beam traverses the body are taken into consideration.

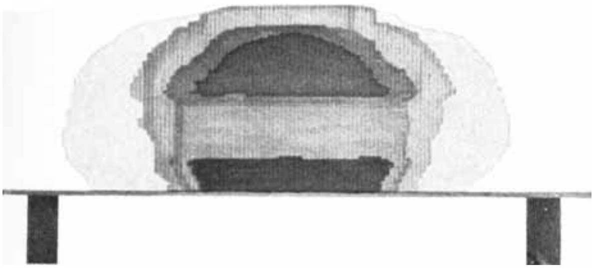

Fig. 3. Same case as fig. 2. Dose distribution obtained for 360° rotation when taking into consideration the treatment table. Field size 18 cm × 20 cm. T/A 0.55.

I believe a great impetus was given to us when Mr Watson of IBM backed TSIEN's experiment using accounting machines in 1954 (TSIEN 1955, 1958). This was one of the first, if not the first, semi-automatic computing systems for external beam treatment planning in radiation therapy. A planar distribution particularly for rotational therapy could be obtained with this system within a realistic period of time and with fairly good accuracy. In 1957 a system for determining the dosage distributions from internal sources was developed (NELSON & MEURK 1958). At this time, we realized that we had to begin to take into consideration the various inhomogeneities that existed within the body and also outside the body. It was impractical to think that these systems would be able to do this and also computers became available to some physics and radiation therapy departments. So it has just been in the past decade that we have really been able to use these instruments to obtain dose distributions correcting for inhomogeneities. As of today, there have been written many and varied radiation treatment planning programs. Some of the most notable programs would be those of SHALEK (1962), LAUGHLIN (1962), CUNNINGHAM et coll. (to be published), VAN DE GEIJN (1970), STERLING et coll. (1961) and others. At the City of Hope National Medical Center, we are presently using a modified version of the Memorial Sloane-Kettering computer program on an IBM 36091 computer.

A typical printer map using this program is shown in Fig. 1. It is from a patient with transitional cell carcinoma of the bladder and shows a distribution obtained by using ^{60}Co therapy and a field size of 13 cm × 10 cm and oscillating the beam through an anterior arc of 90°. The deepest shade represents the most intense area of radiation.

The first heterogeneity that I would like to present is the treatment table. Experiments have been made where an ionization chamber is centered over the table top and the machine is rotated through an arc of 360°. In this manner, an average table absorption factor per rotation can be obtained. However, this does not take into consideration the dose perturbations caused by the table to the

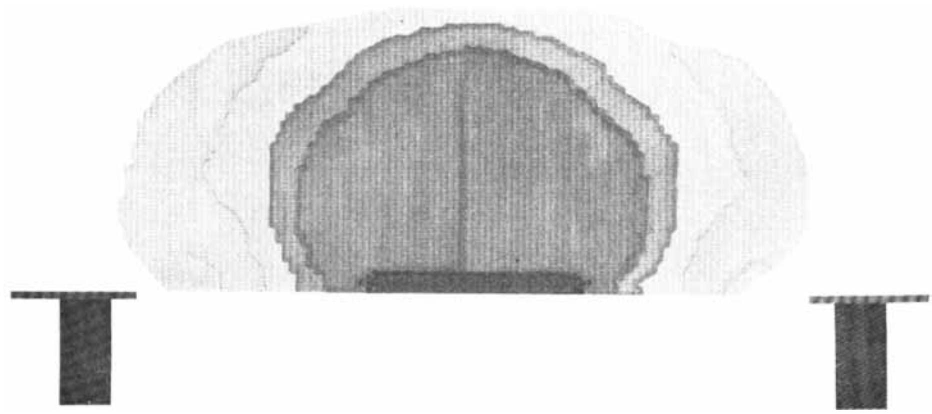

Fig. 4. Same case as fig. 2. Treatment plan showing uniform pelvic dose when treatment table has been modified. Field size 18 cm × 20 cm and 360° rotation. T/A 0.65.

other points of interest in the treatment area. In the following treatment plans the effects of such a table structure and how it can be altered so as to give a more uniform dose throughout the volume of treatment interest will be shown.

A dose map is shown (Fig. 2) taking into consideration only the external contour of a patient's pelvis with no heterogeneities. The small light area in the center represents a T/A of 0.69. However, the dark area, T/A of 0.7, shows a very uniform distribution within the cervical area of this patient with squamous cell carcinoma of the cervix. The treatment technique used was an 18 cm × 20 cm field with 360° rotation. However, the patient has to be supported with a table. A representative cross-section of a patient on a Theratron 80 AECL table is shown in Fig. 3. As can be seen from this treatment plan the dosages within the areas of interest are indeed not homogeneous. The patient is being treated using the same technique but taking into consideration the treatment table. The T/A goes from 0.5 to 0.65 within the pelvic area. The 'hot spots', T/A 0.6, are located over the bladder and on the posterior aspect of the patient including the rectal area. If 4 000 rad were to be delivered to this patient at the T/A of 0.55, the bladder and the rectum would receive approximately 4 700 rad. In view of this, we have modified the table structure so that the patient is supported on a thin mylar sheet stretched between two pieces of a thin aluminium annulus. The same patient is being supported by the modified table top and we have obtained a very uniform dose throughout the pelvic area (Fig. 4). Using this technique, the patient received a pelvic dose of 4 000 rad with a small skin and subcutaneous area receiving 4 300 rad.

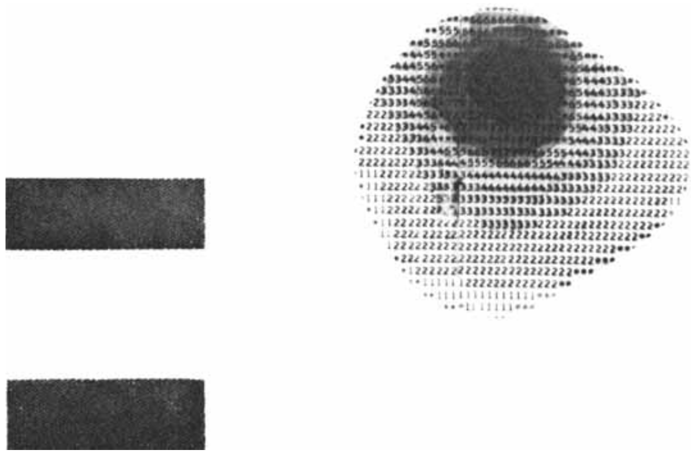

Fig. 5. 360° rotation plan for marginal recurrence of a cervical node using steel table supports for shielding. Field size 4.5 cm × 13 cm. T/A 0.80.

In some cases it is desirable to protect certain areas and yet deliver a very intense dose to an adjacent area. We have found that the steel table supports on the Theratron table can be used for such purposes. The treatment plan of a patient with a marginal recurrence of a cervical node is shown in Fig. 5. The technique employed for this case was a long but narrow field with 360° rotation. The table supports were used in the geometry shown to obtain a shielding of all the areas but the nodal bed. So it is possible to use to an advantage some of the table structures that normally are considered as a disadvantage.

In the past a patient's treatment plan was normally done in the cross-sectional plane. However, a volume of tissue is being treated and the distribution in the sagittal plane could be very important. Fig. 6 is from a patient with a lymphangiosarcoma of the anterior tongue and soft palate. Shown here are the cross-sectional and the sagittal plane distributions. The treatment technique prepared here was a straight anterior field 14 cm × 10 cm. Obviously this would not be the treatment plan of choice, and a distribution in the respective two planes with an anterior and posterior treatment technique with a field size of 14 cm × 10 cm is seen in Fig. 7, but weighing the distribution 2: 1 anterior and posterior respectively. This patient was to be treated to a dose of 5 000 rad to all areas involved using split course therapy. However, it was thought that the patient's spinal cord in the neck area would receive at least the same dose of 5 000 rad or more and, therefore, a compensating wedge filter was added to correct for this high dose area. Using this technique the patient received a dose of 5 000 to

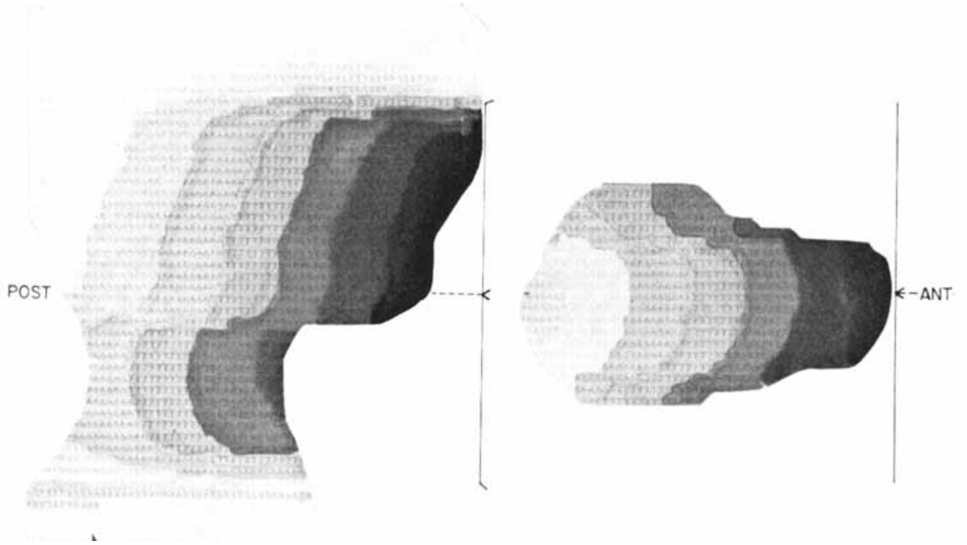

Fig. 6. Distributions in the sagittal plane (left) and the cross-sectional plane (right) for an anterior field, 14 cm × 10 cm, in the tongue and soft palate areas.

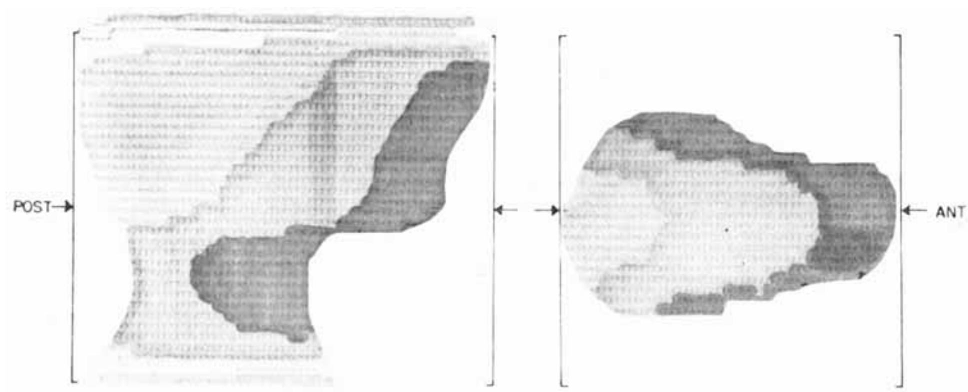

Fig. 7. Same case as fig. 6. Two plane treatment plan of tongue and soft palate areas employing anterior and posterior fields, 14 cm × 10 cm, ratio 2 : 1. 'Hot spot' in the neck. Sagittal plane (left) and cross-sectional plane (right). T/A 0.72.

5 500 rad throughout the tumor volume yet it was considered that the spinal cord received only approximately 4 200 rad. So far in this presentation I have discussed and shown only external heterogeneities and the effects that they had on treatment plans, both good and bad.

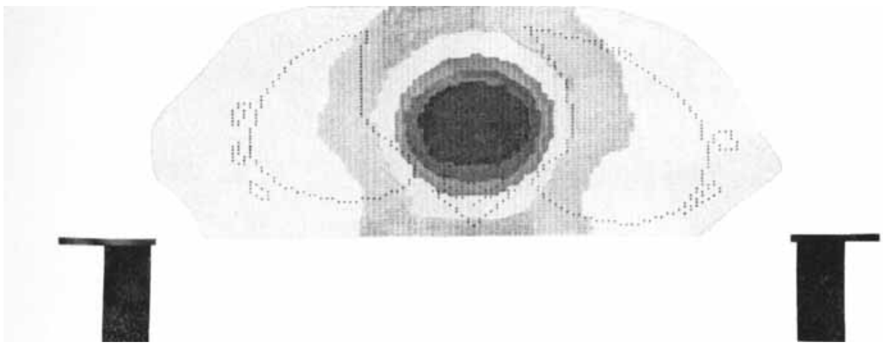

Fig. 8. 360° rotation plan of carcinoma of the esophagus taking into consideration lungs, ribs, vertebral body and treatment table. Field size 7 cm × 18 cm. Internal and external inhomogeneities.

An area that is of even greater concern is internal inhomogeneities. It is relatively easy to determine the geometries of external inhomogeneities relative to the patient when they are being irradiated. However, the location of internal inhomogeneities is more difficult to determine. Therefore, the axial transverse tomographic unit has been developed and made available now to radiation therapists for the treatment planning of their patients. At the City of Hope, we use a Toshiba axial transverse tomographic unit and a simulator. The collimators of the simulator are placed in a plane so that they duplicate the geometries of our Theratron 80 unit. It has proven very useful and decreases patient set up time. In the same room, located 180° from the simulator is the Toshiba tomograph. This instrument has proven already quite valuable to us; however, great care has to be taken when interpreting the tomograms as it is a new field and they are sometimes difficult to interpret. We have found that the monograph by TAKAHASHI (1969), has proven quite helpful along with his comparison to EYCLESHYMER & SCHOEMAKER's book (1938).

The area where the greatest number of inhomogeneities and heterogeneities is obtained is in the thorax area, particularly for rotational therapy for carcinoma of the esophagus. The dose distribution obtained when taking into consideration 15 different inhomogeneities is shown in Fig. 8. These are the lungs, ribs, vertebral body and, of course, the heterogeneities of the treatment table. It would be physically impossible and unrealistic for an individual to be expected to calculate such a distribution manually taking into consideration all these 15 inhomogeneities and heterogeneities.

A tomogram of a patient (Fig. 9) is illustrated with a postsurgical tumor recurrence in the floor of the mouth. From the tomogram the position of the

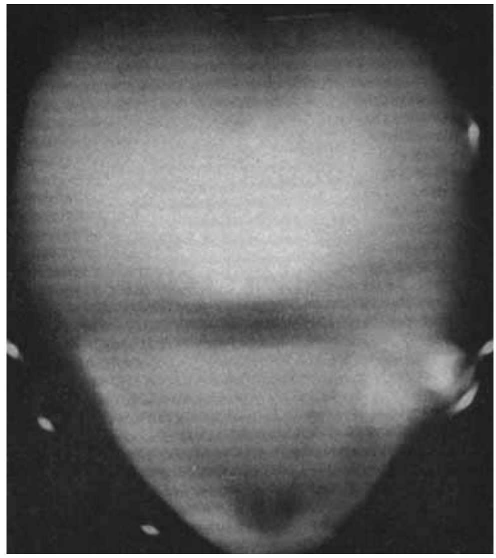

Fig. 9. Axial transverse tomogram of the floor of the mouth.

tumor, the mandible and the vertebral column can be seen. The patient contour (Fig. 10) is shown with the interpretation of this axial transverse tomogram. Also placed in the treatment contour is the area that was considered to be possible tumor extension and possible nodal pathways. This patient was treated using lateral opposed fields with a ratio of 2: 1, left to right. The left field was 7 cm × 10 cm and the right was 6 cm × 10 cm (Fig. 11). This illustrates the increased absorption by the mandible and shows the effect on the treatment when the bone structures are excluded or included in the treatment plan.

In conclusion we are now able to start looking at the distributions within patients as they possibly really exist. This is not on a general view but on each particular patient. Using the simulator, the tomograph and the computer each patient can be evaluated for therapy.

In the very near future many institutions will probably introduce three-dimensional distributions. In this manner we will be able to observe the true radiation dosage to tumor and normal tissues. As a result there certainly will be newer and better programs and techniques available and used in patients undergoing radiation therapy. This knowledge added to that through research in the areas of radiation biology, might enable us to understand more about the effects of ionizing radiations on neoplastic diseases. With all this it is entirely possible that we might be able to have better survival rates in 1980 for the different diseases

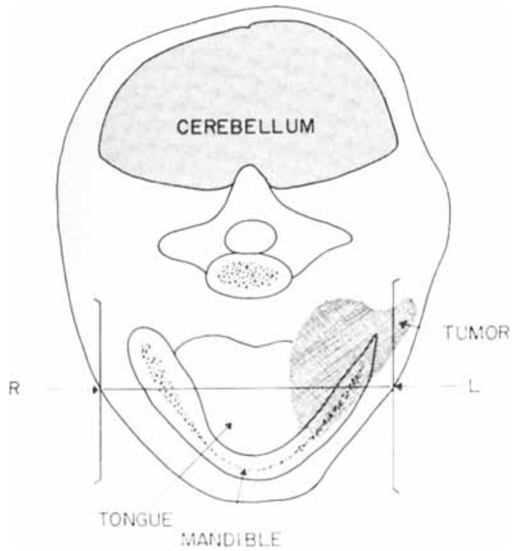

Fig. 10. Same case as fig. 9. Interpretation of axial transverse tomogram showing tumor area and bones located within the section.

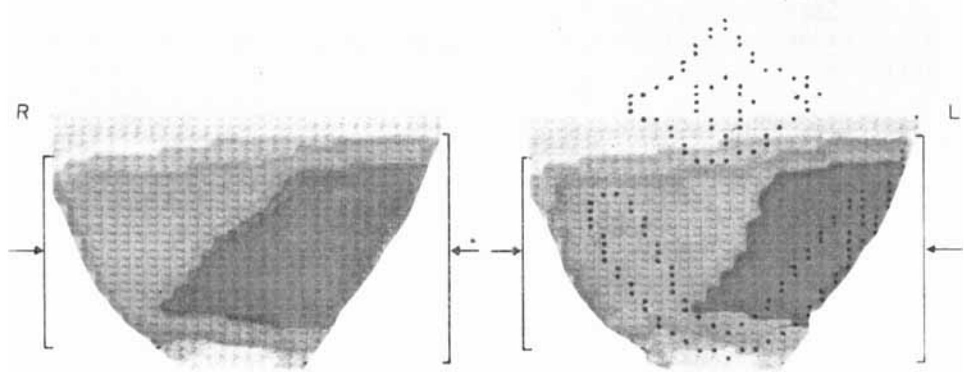

Fig. 11. Same case as fig. 9. Computer treatment plan showing distribution without (left) and with (right) bone. Opposed fields, 7 cm × 10 cm (left) and 6 cm × 10 cm (right). Ratio 2 : 1.

that are treated with radiation therapy than presently exist in 1970. It is only through the cooperation that we get from our colleagues, administrative staffs and industrial companies that makes all these things possible.

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SUMMARY

A brief history of the physical measurements is presented. The effects of external heterogeneities and internal inhomogeneities are also shown. A computer program is used to present the various treatment plans in patients undergoing radiation therapy for different neoplastic diseases. The use of the axial transverse tomography is discussed and presented.

ZUSAMMENFASSUNG

Es wird eine kurze Geschichte der physikalischen Messungen gegeben. Der Effekt der externen Ungleichheiten und internen Inhomogenitäten wird ebenfalls gezeigt. Ein Computerprogramm wird verwendet, um die verschiedenen Behandlungspläne für Patienten, die mit Strahlentherapie wegen verschiedener neoplastischer Erkrankungen behandelt werden, zu zeigen. Die Anwendung der Transversaltomographie wird besprochen und dargelegt.

RÉSUMÉ

L'auteur fait un bref historique des mesures physiques. Il montre l'influence des hétérogénéités externes et des inhomogénéités internes. Il utilise un programme d'ordinateur pour présenter les différents plans de traitement sur des malades soumis à un traitement par les radiations pour différentes affections néoplasiques. Il étudie et illustre l'utilisation de la tomographie axiale transverse.

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