Total Body Irradiation
Dosimetry and Practical Considerations

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Within the medical specialty of Radiation Oncology, Total Body Irradiation (TBI) is considered to be a special procedure. This is because it deviates from more standard radiation treatment techniques in a number of significant ways. The differences are basically due to the fact that the treatment fields for TBI exceed the size of the scattering volume (the entire body) in all directions, and that the irradiated volume is highly irregular in shape. This presentation will identify these differences and offer solutions needed to guarantee accurate delivery of the prescribed dose and to achieve as homogeneous a dose distribution as possible given the available treatment equipment and possible room geometry limitations.

Total body irradiation is used as a preparatory regimen for bone marrow reconstitution of patients with refractory malignancies including leukemia, non-Hodgkin's lymphoma, and neuoblastoma. These regimens typically employ supralethal doses of both chemotherapy and radiation and can produce major toxicity. In order to avoid possible mobidity or even mortality, it is important to clearly understand the techniques available for achieving a homogeneous dose distribution when irradiating the entire body. Additionally, it is essential that prescribed dose calculation methods for TBI be both standardized and reliable. This report will discuss the issues that must be understood to launch a TBI program.

In 1979 a Workshop sponsored by the Children's Cancer Study Group was held in Toronto Canada to discuss Total Body Irradiation. A number of the references used in this manuscript are taken from the material presented at that meeting. The interested reader is encouraged to read other publications from that Workshop that are collected in volume 6 of the International Journal of Radiation Oncology Biology and Physics starting on page 744. These papers were published in early 1980.

DOSE HOMOGENEITY FOR TBI

There are many factors that work to limit dose homogeneity when the total body is the target of irradiation. The thickness of the irradiated volume for TBI tends toward the maximum values encountered for more conventional therapy. This is certainly true if patients are treated with lateral beams, but section thickness is also a problem when AP/PA fields are used. This is because standard techniques for dealing with high-dose regions are not easily applied to TBI. That is, it is not easy to add more field directions to spread the dose in areas where the patient's separation is large. For example, it is not common to combine AP/PA and bilateral fields as a technique of limiting local high-dose regions. This is not done because of the inherent difficulties of field setup would be doubled. Therefore, instead of adding fields, the best practice

is to decrease the maximum thickness in the direction of the beam by treating with AP/PA fields instead of lateral fields. This does not necessarily mean that bilateral fields should never be used. Some investigators have successfully employed bilateral fields to overcome the limitations of small treatment rooms (**5**). Using the lateral field geometry it is possible to drawn up the patient's legs to decrease the field sized needed for full-body coverage. It must be pointed out, however, that techniques for shielding critical normal structures like the lung have not been as cleanly developed for lateral field irradiation as they have been for the AP/PA treatment geometry.

Another method for decreasing the dose heterogeneity that occurs when thick sections are treated with opposed fields is to increase the energy of the beams. The problematic part of this approach is the increased skin sparing that is the result of going to higher beam energy. The concern here is that the target for total body irradiation can be near the skin surface and might be underdosed. The solution is to place a plastic barrier in the beam to create secondary electrons that shift the dose toward the skin surface to maintain acceptable target coverage within the high-dose region that meets the prescription. The topic of skin dose is discussed later in this document.

The effect of beam energy on the shape of a single-field depth dose curve and the summed curve for opposed fields can be large. For the opposed field situation, the difference is most dramatic

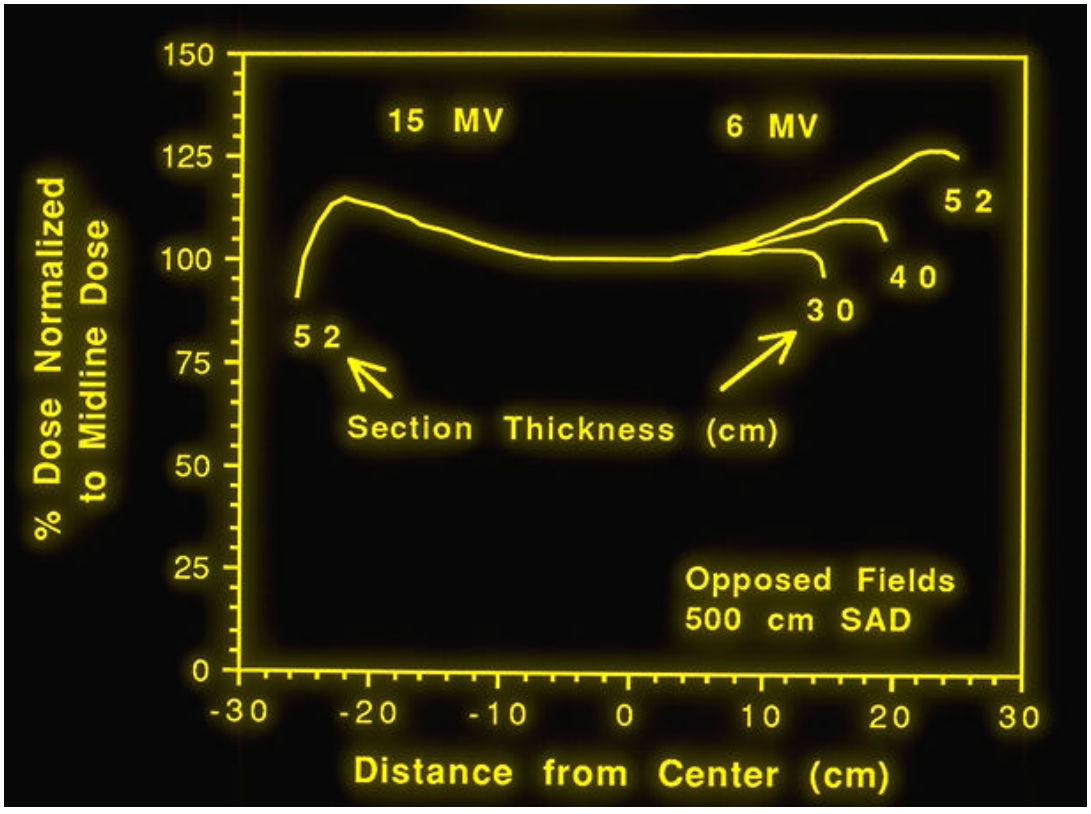

Figure 1

when the thickness of the patient for a particular part of the body is large. **Figure 1** shows how the dose at the build-up depth at either beam entry surface increases with the thickness of the body. For very large separations like the width of the shoulders for an adult patient, the dose near the entry surfaces can be as much as 25% higher than the midline dose for a 6 MV photon energy and 500 cm SAD geometry used for **Figure 1**. This figure also shows that increasing the beam energy from 6 to 15 MV for the same treatment distance bring this dose differential down to about half this amount for the 52 cm section separation.

The change in the max dose compared to the midline dose as a function of treatment distance is shown in **Figure 2**. This figure shows the dose increase near the entry surfaces of the opposed beams for two different SADs (300 and 500 cm) and for two photon energies and for a Cobalt-60 beam. Symmetric hot spots will occur very near the d_{MAX} depths for the individual beams. It is clear from this figure that using Cobalt-60 beams together with a short treatment distance is not recommended when the treatment room geometry dictates the use of lateral fields. In this case, the large separations for adult patients at the level of the shoulders can drive the maximum dose very high. For an AP/PA field arrangement, the problem is less serious and might produce an acceptable distribution. **Figure 2** shows that a 30 cm separation (the approximate thickness at

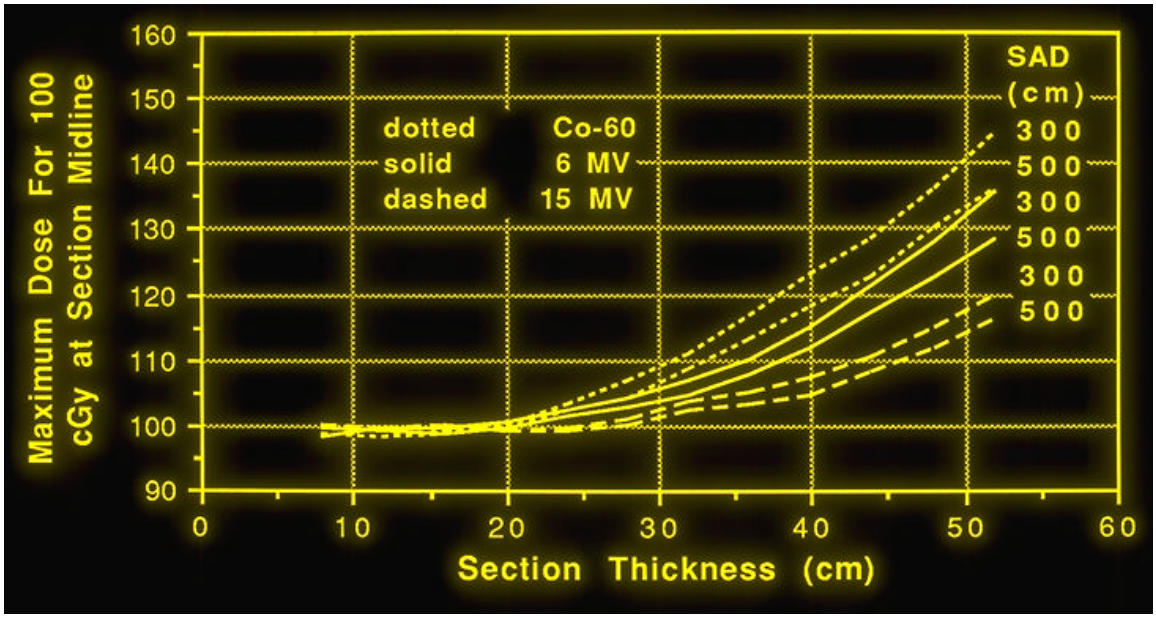

Figure 2

the level of the mediastinum) will give a dose difference comparing the midline to the region of the entry surface that is near 10%. If the patient's thickness at the prescription point (typically the level of the umbilicus) is significantly less, using a Cobalt-60 beam could be acceptable. This will be determined by if the dose to the midline of the mediastinum falls 5% lower than the prescription dose. The typical allowable dose inhomogeneity for TBI is plus or minus 5% relative to the prescription dose. However, another problem that has not yet been discussed might make this treatment unacceptable. That is, there may be much thinner parts of the body that cause the high dose to go well above the +5% limit. **Figure 3** shows the dose increase or

decrease that occurs along the patient's midline as thickness decreases or increases. Two beam energies are shown along with two prescription depths (14 and 20 cm). These prescription depths are chosen as typical values for adult patients treated with either AP/PA fields or bilateral fields. It is also important to point out that this effect is independent of SAD.

Returning to our example of an AP/PA treatment with Cobalt-60 and using the 6 MV photon data as an indicator of the dose excursion, it is easy to see that the decreased thickness for the neck, wrist or ankle regions can easily take the dose homogeneity value well outside the recommended ±5% value. In fact, if these limits are to be adhered to, some measure of beam compensation is needed for even the 15 MV beam.

THE USE OF TISSUE COMPENSATORS TO ADJUST DOSE HOMOGENEITY

Simple tissue compensators that extend completely across the patient can be used to decrease the dose to thinner body sections like the necks or ankles. If compromised room geometry forces the use of lateral fields, much more extensive compensation will be needed. **Figure 3** shows that for a patient with a 40 cm lateral separation at the level of the umbilicus, the dose at the neck with a typical adult separation of 15 cm will be 30-45% higher than the prescription dose. Methods for

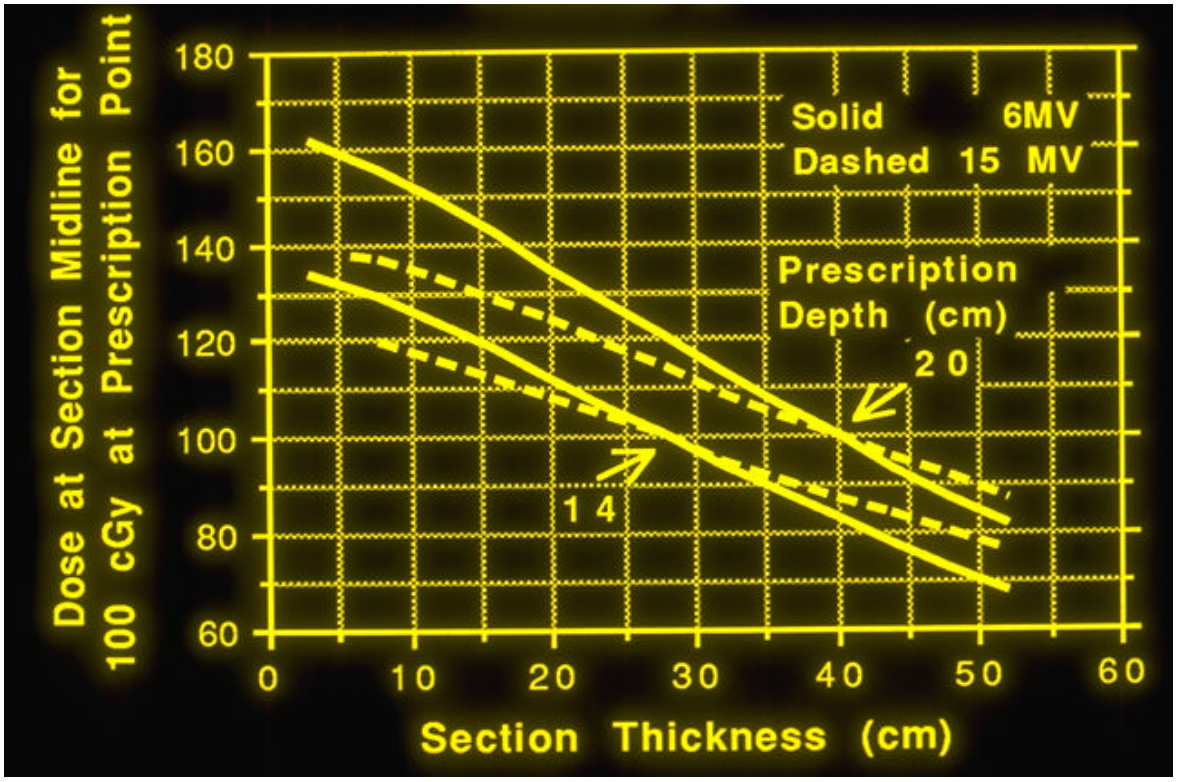

Figure 4

constructing missing tissue compensators for TBI have been described in the literature (**3,5**). The ratio of Tissue Phantom Ratios can be used to determine compensator thickness. Constructing a

compensator to make the dose at the midline of the head equal to the midline dose for the prescription point at the level of the umbilicus is used as an example. Some assumptions about the scattering volumes that determine the TPRs must be made to perform the calculation of compensator thickness. For the TPR at the prescription point, it is assumed that scattered radiation from the head and legs can be ignored. For the head, scatter from parts of the body below the neck is ignored. Thus, the area (A_T) used to find the TPR for the trunk of the body is the patient's lateral separation (for an AP/PA treatment) multiplied by the distance from the top of the shoulders to the groin. The area (A_H) used to find the TPR for the head is the width of the head multiplied by the top of the shoulder to top of the head distance.

A ratio of the Tissue-phantom Ratios is used to determine the compensator thickness. The equation below gives the intensity difference moving from the thicker trunk of the body to the thinner head. The adjustment for any beam profile changes from the center of the beam near the prescription point is accomplished by using the correction factor $C_{profile}$. It is by the amount I/I_0 that the intensity must be decreased by adding a compensator to cover the head region. The

$$I/I_0 = \frac{TPR_T(A_T, d_T)}{TPR_H(A_H, d_H)} \times C_{profile}$$

Following equation can then be used to solve for the compensator thickness *t* that will make the

$$I/I_0 = \exp\left(-\frac{0.693}{HVL} \bullet t\right)$$

dose at the midline of the head equal to the dose midline at the prescription point.

SHIELDING CRITICAL STRUCTURES

Certain sensitive normal tissues might be limited to a dose that is less than the prescription dose. This might be due to the normal dose limit for that tissue, or the particular organ could be compromised by the previous irradiation or chemotherapy. The lungs are an example of an organ system that is particularly sensitive to radiation, easily effected by other therapy regimes, and naturally receives a somewhat higher dose because of reduced density.

There are at least two methods for reducing the dose to critical structures. First, it is possible to place strips of absorbing material completely across the patient to shield these regions. This technique is useful when the amount of adjustment is such that the dose to regions surrounding the critical structure will not be reduced to an extent that they fall outside acceptable dose homogeneity limits. The patient is positioned on his/her side and the gantry is rotated 90 degrees. An AP/PA field arrangement is achieved by turning the gurney on which the patient is lying halfway through the treatment. The compensator can be placed on the treatment unit head using the block tray. When a beam spoiler is used to degrade the skin sparring of the beam, compensators can also be mounted on this device. Port filming (as discussed in more detail in the next section) is used to check the positioning of the compensator.

The disadvantage of using this method for reducing the dose to the lungs is that the dose to the midiastinum will be reduced by an equal amount. For this reason, only small reductions of the lung dose can be accomplished with this technique.

A second method provides much more shielding for the lungs by placing cerrobend blocks between the source of radiation and the patient. Compared to the lead strip technique described above, these alloy blocks are fashioned to conform more tightly to the lung shadow as seen on a radiograph. As the blocks also significantly decreases the dose to the chest wall anterior and posterior to the lungs, the technique uses electron fields to boost the dose for these regions. In order to implement this technique, it is common to treat the patient with AP/PA fields seated on a special device designed to control positioning for this treatment (**10**).

PORT FILMING FOR TBI

Port films for TBI can be obtained by attaching a channel to the wall of the treatment room so that a series of films could be mounted for obtaining this three-film portal image as a single exposure. Films can also be mounted on the couch that supports the patient. Standard radiation therapy cassettes (lead screens) were used for the filming. Port films are commonly used to check the positioning of a lung compensator, and are essential for guaranteeing that adequate margin is achieved at all points around the patient's body. A typical technique for treating TBI rotates the collimator system by 45 degrees to use the corners of the beams at the top of the patient's head and bottom of the feet. This practice is can lead to a marginal miss when the circular primary collimator limits the useful radiation field to a size that is only slightly larger than the width and length of the largest collimator setting. It is important to know the limitations of the field being used for TBI, and to use port filming to verify coverage for each patient's treatment.

POINT MEASUREMENTS

Treatment planning for TBI can stress the capabilities of any RTP system. This is because the sizes and depths of the fields used for irradiation often exceed the limits employed in gathering the data for treatment planning system commissioning. For this reason, point measurements for verifying the prescription dose and the dose distribution are extremely important for TBI. The major dosimeters used for these measurements are thermoluminescent dosimeters (TLD) and diodes. There are some situations where the dosimeter can be placed within a cavity to directly measure a midline, or near midline, dose. A good example is placing TLD into the mouth. For bilateral field irradiation, it is also possible to put dosimeters between the legs to obtain a midline dose. However, in most cases it is not possible to directly measure a midline dose and its value must be determined from entrance and exit measurements. Surface measurements should be taken with appropriate build-up material around the dosimeter. For high energy beams, less than full build-up can be used when a correction to full build-up is made. A treatment planning system can be used to generating a percentage depth dose curve for the actual SSD to the patient's surface at the point of measurement, and this information can be used to correct to the midline position.

Port films can be used to accurately position the dosimeters. The issue here is basically one of verifying the position of the exit dosimeter. The procedure uses small lengths of solder wire to determine dosimeter positions before they are placed for irradiation. Using a determination of lung dose as an example, the wires are placed on the entrance and exit skin surfaces in such a way that it is estimated that a line connecting them goes directly through one of the lungs. This positioning is checked with a port film and adjustments are made as necessary. The dosimeters are then placed for measurement.

PRESCRIPTION METHODS

The generally accepted dose prescription method for TBI uses a single point specification with a statement of the upper and lower dose limits for other parts of the body. Some detailed restrictions for specific critical organs at risk can also be included in the prescription statement. An example of this type of statement would be the maximum allowable dose for the lungs. This prescription method is used by a number of combined study groups using protocols that include TBI. The typical point for dose prescription for TBI used by these protocol groups is the center point (laterally and anterior to posterior) at the level of the umbilicus. Upper and lower dose limits of $\pm$5% of the prescribed dose are typically used, but this dose homogeneity is hard to achieve in practice.

It has already been pointed out that TBI offers a significant dosimetric challenge. In most situations, treatment units are not commissioned specifically for TBI. This means that the scattering volume (the entire body) will deviate widely from the conditions under which the data used to prepare the treatment planning system was gathered. For this reason, two methods have appeared in the literature to handle the problem of calculating the monitor units for TBI. The method proposed by Podgorsak (**9, 11**) corrects measurements made with a large 30x30x30 cm phantom to an infinite phantom situation so that the TG-21 or TG-51 calibration protocol of the AAPM can be strictly followed. These authors point out that the TMR changes significantly as the phantom is enlarged from a 20x20 cm frontal area to an infinite size with the collimator opening held at a maximum. They recommend measuring the TMR specifically for TBI treatments using a series of different phantom sizes. This rigorous approach is not easily implemented and can present problems for some institution with more limited resources.

CALCULATION OF MONITOR UNITS

Another method **(4,13,2)** uses a smaller calibrating phantom (25x25x25 cm or larger) and corrects measurements using standard techniques. The basic assumption in using this method is that for large scattering volumes the removal of extra material around the periphery of the field will not significantly change a measurement at depth in the phantom. More specifically, The correction ratio (Tissue-phantom ratio or tissue-maximum ratio) will not change as side-scatter material is removed for the large scatter volume situation. This assumption has been verified by measurement **(1)** for 6, 10 and 15 MV photons and applies to a midline calculation where at least 6 cm of material is behind the measurement point. Additional measurements have demonstrated that the Peak Scatter Factor, measured with a phantom which exceeds the size of the field, can be used for the situation where the field exceeds the size of the scatter phantom. These findings allow the use of standard data to calculate the treatment unit settings for delivery of the

prescribed dose. The procedure requires separation of the scatter within the phantom from variations in output that occur when the phantom is removed and a build-up cap is placed around the measuring chamber. The latter correction factor is, in practice, hard to measure for higher photon energies where the size of the build-up cap is large. However, since use of the separated data is recommended in the calculation, errors are small. Thus, the TBI field size is used to select the Collimator Size Correction Factor and the smaller patient size (approximated as an equivalent square) is used to select the Phantom Size Correction Factor and the correction ratio (TMR or TPR). Thus, the factors and ratios used in this calculation are different from those ordinarily employed for calculation of the treatment unit parameters.

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