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GENERAL EQUATIONS FOR THE CALCULATIONS OF BIOLOGIC EFFECT RATIOS FOR PARALLEL OPPOSING FIELDS

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In considering the iso-effect relationship in clinical radiation therapy, the use of the NSD concept was proposed by ELLIS (1968, 1969). It is based on the fact that the tissue tolerance dose depends on a simplified time, dose and fractionation factors by the following relationships:

$$D = NSD \times N^{0.24} \times T^{0.11} \qquad (1)$$

where D is the total tolerance dose in rad, N is the number of fractions given, T is the overall treatment time in days and the constant proportionality is termed NSD (the nominal standard dose in ret), a term which relates to connective tissue tolerance.

For a given number of fractions, the value of T depends upon the number of fractions per week and can be approximated:

$$T = K \times N^{1.13} \qquad (2)$$

where K is a constant depending on the number of treatments given weekly (WINSTON et coll. 1969).

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By combining eqs (1) and (2) is obtained:

$$N = \left(\frac{NSD}{d}\right)^{1.573} \times K^{0.173} \tag{3}$$

where $d = D/N$ is the dose per fraction.

Once the tolerance of NSD is established, the partial tolerance is not the sum of each individual combined partial NSD, but rather defined as:

$$PT = NSD \times \frac{m}{N} \tag{4}$$

where N is the number of fractions of the chosen dose which would result in full normal connective tissue tolerance, and m is the number of such fractions actually given (ORTON & ELLIS 1973). The partial tolerance can be summed up only by the concept of eq. (4). By adapting the concepts of NSD and its partial tolerance, two simple systematic formulae in terms of per cent depth doses are derived to compare the biologic effect ratios (BER) of any two points of interest in the treatment volume of two parallel opposing fields, treated either one field or both fields at each session.

Derivation

The resulting biologic effect ratio at the point of interest for two parallel opposing fields treated alternatively one field per session. The following expression is obtained by applying eq. (4):

$$\left[\frac{\frac{1}{2}N(t,n)}{N\left(i_a,\frac{n}{2}\right)} + \frac{\frac{1}{2}N(t,n)}{N\left(i_p,\frac{n}{2}\right)}\right] NSD(t) \times T_{cf} = PT(i_a) \tag{5}$$

$$BER(i_a,t) = \frac{PT(i_a)}{NSD(t)} = \left[\frac{\frac{1}{2}N(t,n)}{N\left(i_a,\frac{n}{2}\right)} + \frac{\frac{1}{2}N(t,n)}{N\left(i_p,\frac{n}{2}\right)}\right] \times T_{cf} \tag{6}$$

where NSD (t) is the maximum tolerance level of normal connective tissue at the tumor bed, PT (i_a) is the sum of the partial tolerance at the location of interested normal tissue other than the tumor bed; t represents the location of the connective normal tissue of tumor bed, i is the tissue of interest to be compared other than t, with the subscripts of a and p of t and i represent the anterior and posterior distances to the surfaces of the skin. T_{cf} represents time correction factor, $N(i_a, n/2)$ and $N(i_p, n/2)$ mean total number of fractions at the point of interest with i_a and i_p respectively when using half fractions of treatments each week. This corresponds to doubling of the total treatment time, i.e., all the treatments from one field with n/2 are given first and the other field with n/2 given later. This is not the actual case and a time correction factor is needed for eq. (5). Concentrating the interest to the tumor site only by using the relationship of eq. (4),

$$\left[\frac{\frac{1}{2}N(t,n)}{N\left(t,\frac{n}{2}\right)}+\frac{\frac{1}{2}N(t,n)}{N\left(t,\frac{n}{2}\right)}\right]NSD(t)\times T_{cf}=NSD(t)$$

$$T_{cf}=\frac{N\left(t,\frac{n}{2}\right)}{N(t,n)} \tag{7}$$

is obtained.

The dose d(i) at i_a and i_p with respect to d(t) and depth doses can be expressed as:

$$d(i_a)=\frac{d(t_a)}{P(t_a)}P(i_a)$$

$$d(i_p)=\frac{d(t_p)}{P(t_p)}P(i_p) \tag{8}$$

where P is the percentage depth dose at the respective sites.

Substituting eq. (7) and (8) into eqs (6),

$$BER(i_a,t)=\frac{1}{2}\left[\left(\frac{P(i_a)}{P(t_a)}\right)^{1.573}+\left(\frac{d(t_p)\times P(i_p)}{d(t_a)\times P(t_p)}\right)^{1.573}\right] \tag{9}$$

is obtained.

Eq. (9) is a general formula which demonstrates the biologic effect ratios of points i_a and t for two parallel opposing fields treated alternately through a single port each day.

The resulting biologic effect ratio at the point of interest for two parallel opposing fields treated daily. The total dose d (sum) of certain normal tissue interested other than the tumor bed which are delivered for each session is:

$$d(sum)=d(i_a)+d(i_p)$$

$$=\left[\frac{d(t_a)}{P(t_a)}P(i_a)+\frac{d(t_p)}{P(t_p)}P(i_p)\right] \tag{10}$$

and by using eq. (4)

$$BER(i_a,t)=\left[\frac{\frac{d(t_a)}{P(t_a)}P(i_a)+\frac{d(t_p)}{P(t_p)}P(i_p)}{d(t_a)+d(t_p)}\right]^{1.573} \tag{11}$$

is obtained.

Eq. (11) is the general formula of the biologic effect ratio of points i_a versus t for two parallel opposing fields treated daily. Both eqs (9) and (11) are based on the same number of fractions per week.

These two generalized equations can be simplified further to find out the biologic effect ratios between the depth of the maximum build-up and the connective tissue of tumor site by the fact $P(i_a)=100$ and $i_a=m$, where m is the depth at maximum build-up point.

$$BER(m,t)=\frac{1}{2}\left[\left(\frac{100}{P(t_a)}\right)^{1.573}+\left(\frac{d(t_p)\times P(s)}{d(t_a)\times P(t_p)}\right)^{1.573}\right] \tag{12}$$

and

$$BER(m,t)=\left[\frac{\dfrac{d(t_a)\times 100}{d(t_p)\times P(t_a)}+\dfrac{P(i_p)}{P(t_p)}}{\dfrac{d(t_a)}{d(t_p)}+1}\right]^{1.573} \tag{13}$$

where eqs (12) and (13) are related to single port and double ports of parallel opposing fields treated daily respectively. s is the thickness of the patient.

A further simplification can be obtained by the following conditions:

(1) Assuming that a constant dose at the maximum build-up point is given for the two parallel opposing fields at each treatment:

$$\frac{d(t_a)}{P(t_a)}=\frac{d(t_p)}{P(t_p)}$$

Then eqs (12) and (13) can be rewritten as:

$$BER(m,t)=\frac{1}{2}\left[\left(\frac{100}{P(t_a)}\right)^{1.573}+\left(\frac{P(s)}{P(t_a)}\right)^{1.573}\right]$$

$$=\frac{1400+P(s)^{1.573}}{2P(t_a)^{1.573}} \tag{14}$$

$$BER(m,t)=\left(\frac{100+P(s)}{P(t_a)+P(t_p)}\right)^{1.573} \tag{15}$$

(2) Assuming that a constant dose at the tumor site is given for the two parallel opposing fields of each treatment:

$$d(t_a)=d(t_p)$$

eqs (12) and (13) can be rewritten as:

$$BER(m,t)=\frac{1}{2}\left[\left(\frac{100}{P(t_a)}\right)^{1.573}+\left(\frac{P(s)}{P(t_p)}\right)^{1.573}\right] \tag{16}$$

$$BER(m,t)=\left[\frac{100}{2P(t_a)}+\frac{P(s)}{2P(t_p)}\right]^{1.573} \tag{17}$$

Table 1

Biological effect ratios for two parallel opposing fields

	Constant skin dose		Constant tumor dose	
	Anterior	Posterior	Anterior	Posterior
Single port per day	1.296 (14)*	1.681 (14)*	1.335 (16)*	1.642 (16)*
Double port per day	1.259 (15)*	1.259 (15)*	1.174 (17)*	1.373 (17)*

* Number of equations applied to content.

Table 2

Maximum tolerance dose (1900 ret) to the tumor bed for two parallel opposing fields

		Constant skin dose		Constant tumor dose	
		Anterior	Posterior	Anterior	Posterior
Single port per day	Tumor dose (ret)	1 900	1 900	1 900	1 900
	Skin dose (ret)	2 462	3 194	2 536	3 120
Double port per day	Tumor dose (ret)	1 900	1 900	1 900	1 900
	Skin dose (ret)	2 392	2 392	2 231	2 609

Eqs (14), (15), (16), and (17) are the simplified results for obtaining biologic effect ratios between the depth of the maximum build-up anteriorly and the connective tissue of the tumor site, which are derived corresponding to the NSD and partial tolerance concept. Biologic effect ratios between the depth of the maximum build-up posteriorly and the connective tissue of the tumor site can also be obtained by simply interchanging t_a, i_a, to t_p, i_p of the above equations. Percentage depth doses depend upon field quality, field size and SSD. Depth dose tables are available from the British Journal of Radiology (1972), Suppl. No. 11. By substituting all the percentage depth doses needed for the above equations, the biologic effect ratios can hence be obtained accurately.

Application

An example is given to show the results of the biologic effect ratio by applying eqs (14–17). A patient of 22 cm thickness is irradiated with two parallel opposing fields (15 cm $\times$ 15 cm) using a ^{60}Co teletherapy unit at 80 cm SSD, in the pelvic region. A maximum tolerance dose to the connective tissue at the site of the tumor bed of 1900 ret is planned to be delivered at a 10 cm (ELLIS & LESCRENIER 1974, WINSTON et coll.) depth anteriorly. The present depth doses which are used for present calculations are obtained from COHEN et coll. 1972. $P(t_a) = P(10 \text{ cm}) = 58.4$; $P(t_p) = P(12 \text{ cm}) = 49.5$; and $P(s) = P(22 \text{ cm}) = 24.9$.

Substituting the above depth dose values to eqs (14–17), the results are listed in

Table 3

Maximum tolerance dose (1900 ret) to the skin for two parallel opposing fields

		Constant skin dose		Constant tumor dose	
		Anterior	Posterior	Anterior	Posterior
Single port per day	Tumor dose (ret)	1 466	1 130	1 423	1 157
	Skin dose (ret)	1 900	1 900	1 900	1 900
Double port per day	Tumor dose (ret)	1 509	1 509	1 618	1 384
	Skin dose (ret)	1 900	1 900	1 900	1 900

Table 1. The biologic effect ratio is always greater than one in this example. The goal of 1 900 ret to the tumor bed is hardly reached without exceeding radiation tolerance of the skin (Table 2). If the maximum tolerance level is 1 900 ret to the skin, the dose to the tumor bed will be reduced accordingly from Table 3. The higher the tumor dose in ret, the greater the chance for curing. So within the same conditions, treating double ports per day is always superior to single port treatments per day, for both constant skin dose and constant tumor dose.

The choice between using the constant skin dose or the constant tumor dose for parallel opposing fields is based on the clinical preference.

Discussion

It is well known that the highest dose level for two parallel opposing fields is mostly located at the depth of the maximum build-up, and the tolerance level of normal tissue at the surface will be reached prior to the connective tissue of the tumor site. The results of treating double fields per session favorable to single field per session are not new. The purpose of this report is to give some systematic analysis from the biologic point of view. Eqs (9) and (11) are generalized equations to compare any two locations within the treatment volume for two parallel opposing fields treated single session daily or double sessions daily. Typical examples of the biologic effect ratio are given for comparing the depth of the maximum build-up and connective tissue of the tumor site, as shown in eqs (14–17). All of the above derivations and arguments are based on the NSD concept and its partial tolerance concept. A real numerical ratio can be obtained by using the above equations, which give a better understanding to realize the dosage distribution at different treatment plans and locations.

SUMMARY

The tolerance level of normal tissue, which is the concept of NSD, is the limiting factor in radiation therapy. It is well known that the two parallel opposing fields should be treated at each session instead of alternating one field per session. The biologic effect ratios between the normal tissue at the depth of maximum build-up and the midline for parallel opposing fields were published by Ellis et coll. General formulae are now presented providing biologic effect ratio at any two locations in terms of per cent depth doses in the treatment volume for parallel opposing fields. Examples at the depth of maximum build-up and certain depth of the connective tissue at the tumor site are also given.

ZUSAMMENFASSUNG

Das Toleranzniveau des normalen Gewebes, welches das Konzept der NSD ist, bildet den begrenzenden Faktor bei der Strahlentherapie. Es ist wohl bekannt, dass die beiden parallelen gegenüberliegenden Felder bei jeder Behandlung behandelt werden sollten anstelle umwechselnd ein Feld per Behandlung. Die biologischen Effekt-Verhältniswerte zwischen den Normalgeweben zu der Tiefe des maximalen 'Build-up' und der Mittellinie für parallele gegensätzliche Felder sind von Ellis et coll. publiziert worden. Generelle Formeln werden nun gegeben, um biologische Effekt-Verhältnisse an jeder von zwei Lokalisationen in Begriffen von Prozent-Tiefendosen im behandelten Volumen von parallelen gegensätzlichen Feldern zu erhalten. Beispiele für die Tiefe des maximalen 'Build-up' und einer gewissen Tiefe für das Bindegewebe am Platze des Tumors werden gegeben.

RÉSUMÉ

Le niveau de tolérance du tissu normal, qui est le concept de la NSD, est le facteur limite dans le traitement par les radiations. Il est bien connu que deux champs parallèles opposés devraient être traités à chaque séance au lieu d'alterner un champ par séance. Les rapports d'effet biologique entre le tissu normal à la profondeur d'accumulation maximale et sur la ligne médiane pour des champs parallèles opposés ont été publiés par Ellis et collaborateurs. Les auteurs présentent maintenant des formules générales donnant le rapport biologique pour deux localisations quelconques en terme de pourcentage de dose en profondeur dans le volume de traitement pour les champs parallèles opposés. Ils donnent aussi des exemples à la profondeur d'accumulation maximale et à une certaine profondeur du tissu conjonctif au siège de la tumeur.

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