行政院國家科學委員會專題研究計畫 成果報告

醫學大學導航螺旋光子刀在患者的全身劑量評估(I)
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行政院國家科學委員會專題研究計畫成果報告

醫學大學導航螺旋光子刀在患者的全身劑量評估(I)

Evaluation of whole-body dose from TomoTherapy delivery at Medical University Hospital

計畫編號：NSC 97-2221-E-040 -008 -
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摘要

第一年:TLD-100 進行田口式方法，以得到熱發光劑量計 TLD-100 (thermoluminescence dosimety, TLD) 於本校附醫 6 MV 的導航螺旋光子刀(TomoTherapy)劑量上，全部以田口博士方法得到最佳化量測條件。射束劑量以 50, 100, 150 cGy 進行 TLD 上效準，每一個測量點佈植三個 TLD，後求平均，共有九組不同計讀條件，來參照改變，計讀條件是以起始溫度、加熱速度、預熱時間及最高溫度，四個最佳化條件為(1)50℃起始溫度、(2) 3 ℃/s 加熱速度、(3) 5*min.* 預熱時間及(4) 250℃最高溫度，另外,最佳化條件主要與起始溫度、加熱速度及最高溫度有關，而下半年進行設計與研發重量 50 至 90 公斤之自行擬人型假體。

關鍵字: 導航螺旋光子刀, 洩漏輻射, 田口式方法, 熱發光劑量計

1 ABSTRACT

The first year is to optimize various TomoTherapy doses via TLD-100 use the Taguchi method. The scattering and leakage x-ray was produced by Hi-Art helical TomoTherapy at 6 MV of CSMUH. The TLD-100 readout system was optimized for various radiotherapy beam doses using the Taguchi method. The beam doses were 50cGy, 100cGy and 150cGy, and the measured data in each group were averaged from three TLD-100 chips. A total of nine combinations of four parameters were arranged, in the manner suggested by Taguchi. The four parameters were defined as initial temperature, heating rate, preheat time and maximum set temperature of the readout system during TLD reading. The loss function η adopted herein was specifically defined to satisfy the requirements of both sharp linearity and good reproducibility of the TLD reading at various radiotherapy beam doses. The optimized values were (1) 50 ℃ for initial temperature, (2) 3 ℃/*s* for heating rate, (3) 5*min.* for the TLD preheat time and (4) 250 ℃ for the maximum temperature for TLD reading. Additionally, the parameters that dominated the TLD readout were initial temperature, heating rate and maximum temperature setting for TLD reading; and the minor parameter was (3) TLD preheat time before reading. We will design and develop 50 to 90 kg phantoms in the last year.

Keywords: TLD readout, Taguchi, optimization, dynamic robust design

2. INTRODUCTION

In this work, the TLD-100 readout system for various radiotherapy beam doses was optimized using the Taguchi methodology. Many researchers consider the use of thermoluminescent dosimeters (TLD) to be the most cost-effective approach for performing external dosimetry audits (Arib 2006, Svensson 1993, Derreumaux 1995). A well-calibrated TLD readout system not only determines specific doses with good reproducibility but also can be used with a wide range of doses. This unique criterion for the application of TLD is critical to confirm radiotherapy beam doses, since the dose that is given in a single treatment is typically 30-300 cGy. Researchers have also noted the tendency to adopt the TLD, and several published papers have offered recommendations for optimizing the TLD readout parameters. Dr. Arib optimized the characteristics of TLD by specifically adjusting the amount of LiF powder in each capsule, the elapsed time between the irradiation and the reading of TLD, and the nitrogen flow during measurement (Arib 2006). Dr. Samei optimized the allocation of a glow curve for TLD in the heating process (Samei 1994). Dr. Branch employed Monte Carlo simulation to predict the glow curve of optimally performing TLD (Branch 1999). However, some recommendations made in these studies are very controversial since these studies focused mostly on a single parameter despite the existence of cross interactions among parameters of the TLD readout system. Therefore, this work presents an optimized process for evaluating the TLD absorbed dose in various radiotherapy beams based on the Taguchi methodology.

Twenty-seven TLDs were randomly categorized into nine groups and irradiated under various cGy doses to optimize the TLD readout system. Several parameters were simultaneously considered for optimization following Taguchi. The cross interactions between parameters during the optimized process were also considered to capture the complexity. Since the quality requirements for a TLD reading include both reproducibility of specific doses and of the responds to various doses, a dynamic robust design is presented and the optimization process and Taguchi methodology are discussed herein.

3 TAGUCHI ANALYTICAL METHODOLOGY

As a highly effective means of designing a high-quality system, the Taguchi method provides both an efficient and systematic approach to design for optimizing performance and quality. Furthermore, a Taguchi parameter design can optimize performance by setting the operative parameters and reducing the fluctuation of system performance due to any source of variation. The Taguchi method utilizes a special design of orthogonal arrays to obtain extensive parameter data from only a few experiments. Parameter design attempts to optimize TLD readout parameter values to imply a convincible and reliable dose report system. Moreover, the obtained optimal TLD readout parameter values should be insensitive to variation in environmental conditions and other factors. Moreover, a statistical analysis of variance (ANOVA) is utilized to determine which parameters are statistically significant. Combining S/N and ANOVA analysis can be used to identify the optimal combination of TLD readout parameters (Tarng 1998, Pan 2001, Pan 2004, Pan 2005).

3.1 Orthogonal Arrays

In contrast to other optimal analytical methods, Taguchi's method determines both the optimal result from finite analytical data and the dominant factors involved in the optimization for TLD reading from finite analytical data. This method has been widely applied in precise manufacture (Yang 1998, Miyazawa 1986, Tam 1993) and other fields (Al-Bsharat 1996, Miyazawa 1993, Lee 1992, Loh 1993, Tak 1989, Hassan 1997). In this study, the four essential TLD readout parameters are obtained as (1) the initial temperature setting for the reading of TLD, (2) the heating rate during reading process, (3) the TLD preheat time before reading and (4) the maximum temperature for TLD reading, and these four parameters were concerned altogether with three different levels of each to optimize the suggestion. Thus, a total of 81 (3×3×3×3) different combinations were considered. However, according to Taguchi, the samples could be organized into only nine groups and still yield results with the same confidence as if they were to be considered separately (Taguchi 1990). Table 1 shows the arrangement of the samples into nine groups according to Taguchi. The numbers indicate the various experimental layouts or levels of the different factors.

3.2 Analysis of Variance; ANOVA

A loss function η is defined to identify any deviation between experimental values and desired values. Dr. Taguchi recommends using a loss function to measure deviations of the performance characteristics from desired values to suppress effectively interference by noise. The loss function value is further transformed into a signal-to-noise (S/N) ratio. Performance characteristics fall into three classes; they are lower the better, higher the better and nominal is best. Each has its own S/N ratio definition to be used in the computation of the optimal combination of parameter. A larger S/N ratio always corresponds to optimal quality characteristic, regardless of category. Restated, the optimal level of operative parameters is that with the highest S/N ratio, and vice versa (Taguchi 1990). Thus, the TLD absorbed dose under various radiotherapy beam doses from each group are calculated and reorganized as follows (Phadke 1989):

$$\eta = -10\log\left(\frac{\mathrm{S}^2}{\bar{\mathrm{y}}^2}\right) \tag{1}$$

$$S = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \beta\times x_i)^2}{n-1}} \tag{2}$$

where η is the inspection index, defined as the signal to noise ratio (S/N unit:*dB*). S is the gross deviation between practical released counts (y_i) and theoretical prediction for the given dose x_i of radiotherapy beam. The β is exactly gradient of the given dose as a function of TLD reading. An ideal TLD dosimeter readout system should reflect the given dose with good reproducibility (smaller S), and sharp gradient (larger β) in real. Thus, A larger value of η is considered preferable herein (this is existed only under either smaller numerator, S, or larger denominator, β). In addition, a higher η (S/N) value also indicates a superior performance for TLD readout system, since the major signal dominated the noise. y_i is the counts of TLD reading in each group, i, and n is the repeating number in each group, 9 (3 repeats in 3 various radiotherapy beam doses, 3 × 3). Define S_m, S_A, S_T and S_E as follows:

$$S_m = \frac{(\sum \eta_i)^2}{n} \tag{3}$$

$$\mathrm{S_A} = \frac{\sum \eta_{\mathrm{A}}^2}{\mathrm{n}} - \mathrm{S_m} \tag{4}$$

$$\mathrm{S_T} = \sum \eta_\mathrm{i}^2 \text{ - } \mathrm{S_m} \tag{5}$$

$$\mathrm{S_e} = \mathrm{S_T} \text{ - } \sum \mathrm{S_A} \tag{6}$$

where *Sm* is the average of the squares of the sums of the η, and η_i is the specific inspection index in group *i*. S_A is the sum of squares correlated to various reading parameters *A*; the ηA_i is the inspection index correlated only to the specific parameter *A*; and *N* is the number of samples in each group. The various kinds of *A* are initial temp, heating rate, preheat time before reading and maximum temp. of the TLD readout system. The corresponding number, *N*, is all 9 herein. S_T is the sum of squares of the variance and S_E is the sum of squares of the errors correlated only to the specific parameters *A*. Define F_{A0} as the index of $F - test$ for checking the specific parameter, *A*, and given as:

$$F_{A_0} = \frac{S_A / f_A}{S_E} \tag{7}$$

where f_A is the degree of freedom for that specific consideration, which values are two for all the TLD readout parameters herein. S_A/f_A is also defined as the variance; V_A; of the specific parameter *A*. The $F - test$ which is first proposed by Dr. Fisher (Fisher 1925) is an auxiliary tool for inspecting the dominant factors involved in TLD readout system. The contribution of the specific parameter dominated the dosimeter reading if F_{A0} equals approximately to or greater than the index $F_{0.05}$ (Pearson 1972). Thus, the larger the F_{A0} value, the more dominant the parameter in TLD dosimeter readout system.

4. EXPERIMENTAL SETUP

Twenty-seven standard TLD-100 loose chips ($3.2 \times 3.2 \times 0.89\ mm^3$) were obtained from the Harshaw/Bicron Company. The TLDs were randomly categorized into nine groups, each of three TLDs. Table 2 presents the manipulation of TLD readout parameters, which followed Taguchi's suggestion exactly [cf. Tab. 1]. Each group of TLDs was irradiated in three various radiotherapy beam doses, 50cGy, 100cGy and 150cGy, as determined by the Varian 21EX linear accelerator (LINAC) with 6MV. The LINAC was located at the Chung Shan University Hospital (CSMUH). As clearly depicted in Fig. 1, each group of TLDs was placed 5cm deep in the center of a 15cm-thick solid water phantom and the SDD (source to detector distance) was 100cm. The TLD assigned dose was confirmed using a Markus plane type ion chamber (*Victoreen model PTW* 23343). The ion chamber was inserted into a specific tunnel inside the same solid water phantom to obtain the absolute dosimetry as given to TLD. The irradiated TLD readout was obtained using a Mikro Lab RA94 TLD reader/analyzer and by annealing in furnaces (*Barnstead Int. Co. model* 47900) coupled with an oven/Incubator (*model* 19200) for 400℃ 1 hour and 100℃ 2 hours. Furthermore, the TLD was cooled for at least seven days for next exposure to suppress the residual dose effectively.

4.1 Self-developed mathematic (SDM) phantoms

We have developed three SDM phantoms with anthropometric-shaped skeletons constructed of acrylic and epoxy-resin to simulate averaged male body weight 30, 50 and 70 kg. Acrylic and epoxy-resin were chosen as the neutron and photon transport properties. The SDM phantom was GSF adult male mathematical models that heights and masses of the whole bodies, as well as the masses of internal organs are based on the ICRP reference man and calculated from external neutron and photo irradiated in radiotherapy exposures, using Monte Carlo methods, data published by ICRU report 48 was formulated as follows: skeleton-cortical bone with a physical density 1.486, skin, 1.105 and lung-tissue substitute 0.296 g/cm^3, respectively (ICRU 48, 1992). The SDM phantoms were based on the general human design (ICRU 48, 1992); each was constructed of 31 slices, representing the head, neck, torso, abdomen, but without two arms and legs. Table 7 lists dimension, physical properties and body mass index (BMI) of phantoms.

5. RESULTS AND CONFIRMATION OF TLD READOUT

Table 3 presents the original three TLD readings under various radiotherapy beam doses (50cGy, 100cGy and 150cGy) for the nine groups of randomly assigned TLDs. Accordingly, twenty seven TLD chips were analyzed. Table 4 plots the analytical results for the TLD readout under various radiotherapy beam doses (50cGy, 100cGy and 150cGy). The β was an exact gradient of the given dose as a function of TLD reading. S refers to the gross deviation between practical counts and regressive prediction [cf. Eq. 2]. As Tab. 4 clearly shows, group 8 had the highest β of all nine groups and therefore had the steepest gradient for the given doses versus TLD readings for various radiotherapy beam doses. Group 1 revealed the lowest statistical deviation and thus had the highest reproducibility of all groups. Group 1 also had the highest η value which fact indicates that this group achieved the best compromise between β and S. Restated, the high regressive slope β and low statistical deviation S were both optimal when the TLD readout parameter was the same as that in group 1. To further confirm the optimal recommendations of the TLD readout system, forty-eight TLDs were randomly categorized into two groups. In one group, the previous settings [cf. group no. 8 in Tab. 4] were applied, and in another group, the optimal recommendation in this study [cf. group no. 1 in Tab. 4] was applied. Each group was separated into eight packs, and each pack with three TLDs sealed inside was inserted into a rando Phantom for LINAC exposure. Figure 3 shows the calculated dose curve and the TLD reading for different settings along segment AB [cf. Fig. 2]. Table 5 lists the TLD readout system parameters for either the previous setting or the optimal recommendation. The cumulative percentage error as implied in the plot was defined as

$$cumulate \quad error\% = \sqrt{\frac{\sum_{i=1}^{n}[(D_{cal.} - D_{TLD})/D_{cal}]^2}{N}} \times 100\% \tag{8}$$

where D_{cal}. and D_{TLD} represent the calculated dose from computerized treatment plan and practical TLD readout under various settings at the n_{th} data acquisition point. Notably, the value of N is 8 [cf. Fig. 3]. The percentage error can be optimized from 3.40% to 1.74%, which indicates good consistency between theoretical calculation and practical evaluation; although the gradient (*i.e.* linearity) is decreased from 4350.2 to 4152.7 [cf. Tab. 4].

6. DISCUSSION

6.1 Dominant Parameters of TLD Readout

The dominant operating parameter for the TLD readout system can also be confirmed from the $F - test$ [cf. Eq. 8]. Table 6 shows the ANOVA and F-test results for the dynamic TLD readout system. The final column in Tab. 6 provides the percentage contributions of specific operative parameters to the effectiveness of the TLD readout and is considered significant if the percentage exceeds 95% (FIsher 1925). Accordingly, (1) initial temperature, (2) heating rate and (4) maximum temperature setting for the TLD readout are the dominant parameters since the confidence levels for these three parameters are either exactly or approximately 100%. The (3) TLD preheat time before readout can be considered a minor parameter since the specific confidence level is only 88.5%. Therefore, the preheat time of the TLD chip before the readout need not be increased to maintain an output that reaches the required confidence level. Rather, holding for just 5 min. yielded reliable results. However, the other three dominant parameters were addressed differently since they decisively affect the real TLD readout. To further examine the characteristics of the glow curve of TLD-100 chip in other works (Ozturk 2003, Yossian 1995, Kim 2004, Sabini 2002, Wei 2003), the low initial temperature and heating rate in the readout of the TLD chip (as evaluated herein) are not always as in the protocol used in other applications. The radioactive source that activates the TLD chip remains an important issue since the given energy excites electrons from ground state to various meta-excited states. The high-energy photons generated by the 6MV linear accelerator can deposit their energy into a deep layer of the TLD molecular structure using primarily small-angle Compton scattering (Turner 1995). Therefore, a low initial temperature and a slow TLD chip heating rate can be used in the readout process in order to help the TLD molecular structure release most of the trapped electrons in the layers. Figure. 4 plots three typical glow curves of the TLD chip during the readout process. The figure clearly shows the same TLD-100 chip placed 5cm deep in the center of a 15cm-thick solid water phantom with 100cm SDD then exposed under three different sources (a)6MV LINAC 49.37cGy, (b)6MV LINAC 4.94cGy and (c)diagnostic X-ray (120kVp, 70mAs) 6.261mGy for comparison. Additionally, diagnostic X-ray is also adopted as a radioactive source for further comparison of TLD in wide range. The corresponding glow curves reveal diverse characteristics in real TLD counting cases. Accordingly, the optimal TLD readout approach is still uncertain in many applications (Ozturk 2003, Yossian 1995, Sabini 2002).

6.2 Cross-Interaction between Parameters of TLD Readout

The Taguchi method not only determines the Quality Control (QC) dominant parameters. It is also an effective algorithm for elucidating specific cross-interactions among parameters. The unique orthogonal arrangement of different parameter levels maintains the same frequency of different levels among nine groups. Therefore, the obtained data can also be rearranged to elucidate the cross-interaction between the parameters [cf. Tab.1] (Pan 2004, Pan 2005). Figure 5 presents three cross interactions between pairs of parameters. Parts (A), (B) and (C) plot initial temp. *vs.* heating rate, initial temp. *vs.* max. temp., and heating rate *vs.* max. temp., respectively for the TLD readout. In part (A), three lines barely intersect, indicating the absence of cross interaction between these two parameters. This situation is preferred for the real evaluation of the TLD readout system since the two dominant parameters are weakly correlated. The S/N value declines with the initial temperature setting for all three heating rates in the TLD readout process. Additionally, the S/N value reaches maximum when both initial temperature and heating rate are at minimum (50℃ and 3℃). The initial temperature and maximum temperature in the TLD readout process interact moderately with each other [cf. Fig. 5 part.B]. The S/N value declines as the initial temperature falls for all three maximum temperature settings. Additionally, the

S/N (η) value curve decreases rapidly and intersects with the η curve as the initial temperature in the TLD readout increases from 50℃ to 70℃. Therefore, the S/N value is maximal at either the lowest initial temperature or the lowest maximum temperature of the TLD readout (50℃ or 250℃). The outcome is consistent with the primary analytical results (indicating that both the initial temperature and the maximum temperature should be at their lowest setting) [cf. Sec. 5, Tab. 4]. The follow-up verification of the optimization confirms this assertion. Part (C) reveals the most complicated cross interaction among the three cases. The S/N (η) fluctuates markedly as the heating rate changes at various maximum temperature settings of the TLD readout system. Also, the η trends vary among the three settings of maximum temperature of the TLD readout. However, since the maximum η remains unchanged and is held in its preliminarily settings (with the combination of parameters held as in group 1 [cf. Tab. 2]), the optimal setting for the TLD readout system is initially derived despite the complex cross-interaction between these two particular parameters. The complexity of the cross interaction between the dominant parameters also complicates the optimization of the TLD readout system since the unpredictable variation of the η value is associated with the various parameter combinations. In this analysis the benefits of the Taguchi method are therefore evident.

6.3 Dynamic and Static Robust Design

The proposed robust design is superior to the conventional static design. The dynamic robust design optimizes performance in more than just a single situation. The static design emphasizes only a single requirement for a specific condition. The S/N (η) values in dynamic design are higher-is-better for all three radiotherapy beam doses. Therefore, evaluating the η trend requires both good reproducibility in a particular dose and strong linearity among all three given doses. Accordingly, η is defined as [$-10 \, log \, (S/\beta)^2$] while the definition of only S or only β does not completely fulfill the confidential requirement in evaluating the various doses in this work (the definition of η should be precisely compared with Eq. 1, 2). When considering only β, as defined by the most static design, then the group 8 setting would be optimal. The parameters combination for the TLD readout system in group 8 is (1) 100℃ for the initial temperature setting for the TLD readout, (2) 6℃*/s* for the heating rate during the readout process, (3) 5*min.* for the TLD preheat time before the readout and (4) 300℃ for the maximum temperature in the TLD readout [cf. Tab. 2]. The largest β observed for group 8 is interpreted as the maximum linearity of beam doses. However, the S value in group 8 was almost double that of group 1 (14369 and 7923 for group 8 and 1, respectively). Accordingly, if η is redefined as [$-10 \, log \, S^2$], evaluating the loss function only appears in improving the reproducibility of TLD readout under various radiotherapy beam doses despite the linearity of the regressed correlation. The lowest *S* value happens to equal that in group 1, which is consistent with the findings of the dynamic evaluation. This coincidence does not imply the most dynamic robust design since the definition of η and the correlated calculation differ entirely. Eventually, the definition of the loss function, S/N (η) is manipulated to reflect the optimal results from various perspectives and thus change the calculations for optimization.

7 CONCLUSION

The TLD-100 readout system was optimized for various radiotherapy beam doses using the Taguchi methodology. The loss function η was defined as $[-10\ log\ (S/\beta)^2\ ]$ to achieve sharp linearity as well as good reproducibility of the TLD readout at various radiotherapy beam doses. The related calculation and discussion were based on a dynamic robust design in the optimization process. The suggested optimal parameters for TLD readout system herein were (1) 50℃ for the initial temperature, (2) 3℃*/s* for the heating rate, (3) 5*min.* for the TLD preheat time before readout and (4) 250℃ for the maximum temperature setting for the TLD readout. The dominant TLD readout parameters were (1) initial temperature setting, (2)heating rate and (4)maximum temperature setting, and the minor parameter setting was (3)TLD preheat time before the readout. The follow-up evaluations of the cross interactions among the parameters revealed no significant conflicts among dominant parameters. However, the heating rate and maximum temperature of the TLD readout must be carefully set since a complex cross interaction might occur between these two parameters. The dynamic robust design was practically superior to the static one since the definition of loss function η more closely met the requirements of an actual TLD readout.

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10 FIGURE LEGEND

Fig.1 (A) The Varian 21EX linear accelerator (LINAC) with 6MV. Each group of TLDs was place 5cm deep in the center of a 15cm-thick solid water phantom and the SDD (source to detector distance) was 100cm. (B) the close up view of the TLD tray inside the 15cm-thick solid phantom.

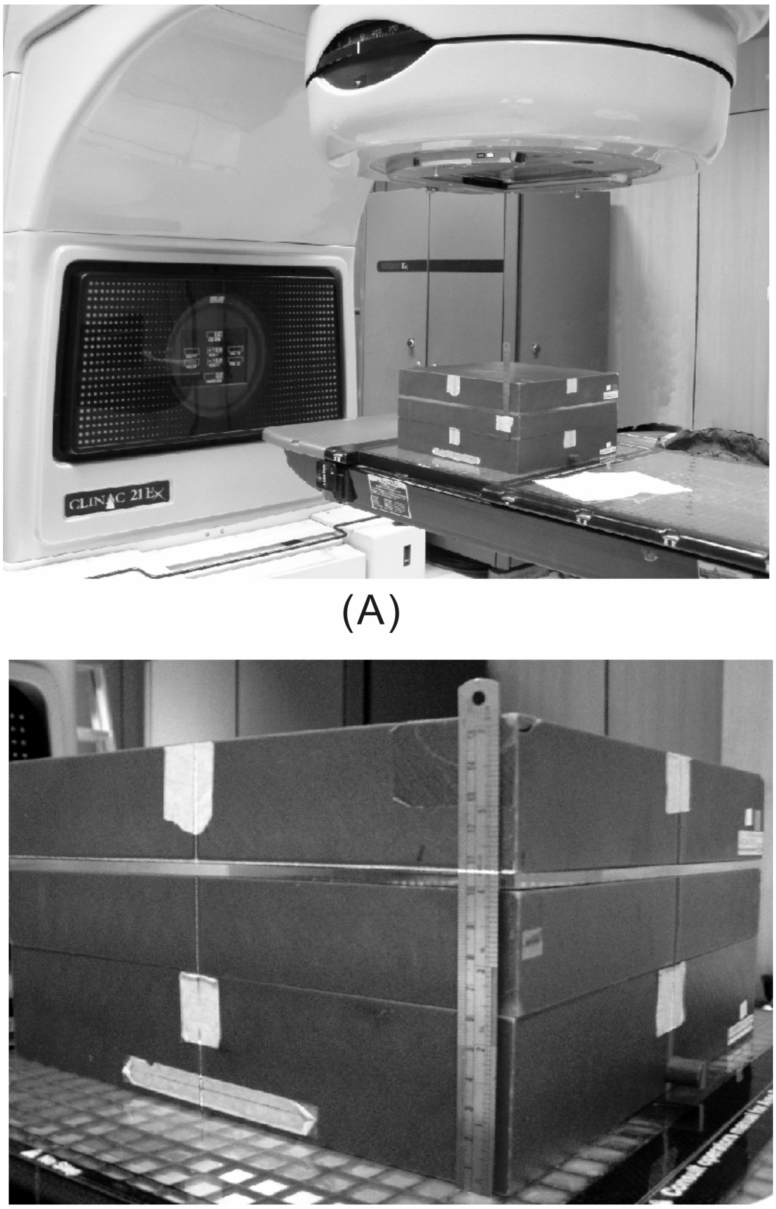

Fig. 3 The TLD responsed dose for either previous setting or optimized recommendation of the TLD readout system parameters. The continuous dose curve was adopted from the computerized treatment plan [cf. Fig. 2]

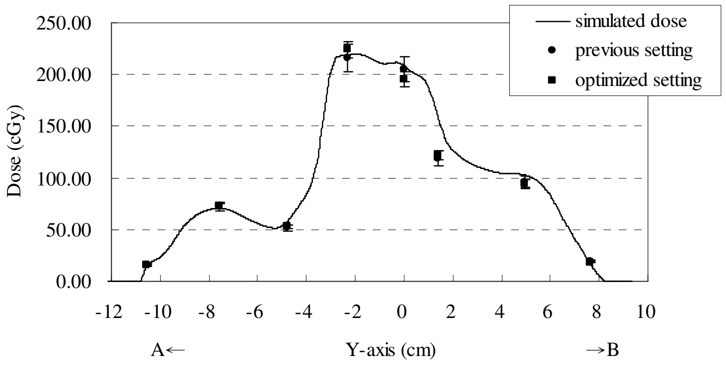

Fig.4 (A) The 3 different glow curves of TLD versus the temperature of TLD, the temperature is indicated in Celsius degree, ℃. The same TLD-100 chip was placed 5cm deep in the center of a 15cm-thick solid water phantom with 100cm SDD, then exposed under three different sources (a)6MV LINAC 49.37cGy, (b)6MV LINAC 4.94cGy and (c)diagnostic X-ray (120kVp, 70mAs) 6.261mGy. (B) The close up view for (b) and (c).

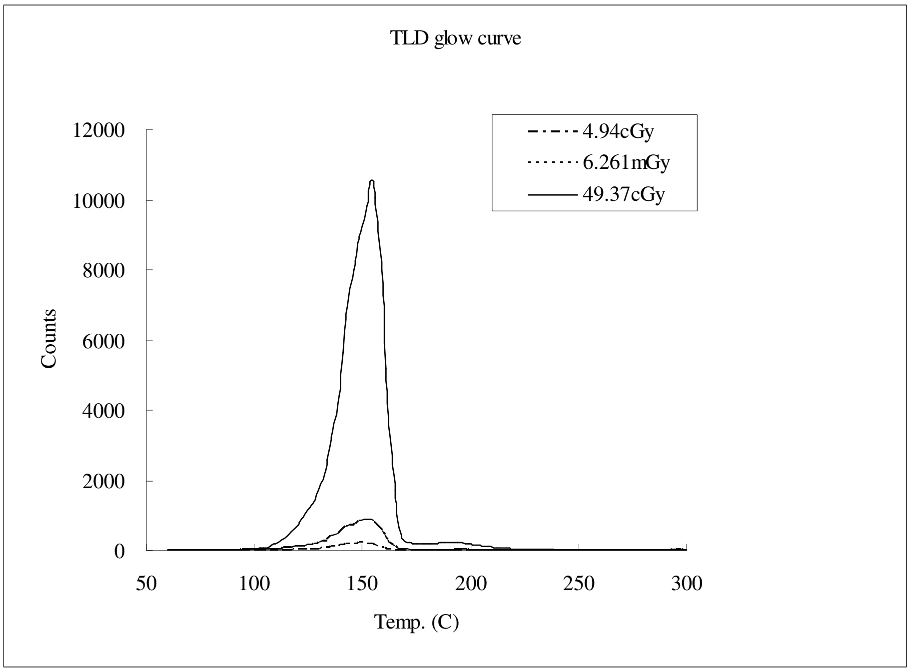

Fig. 4(A)

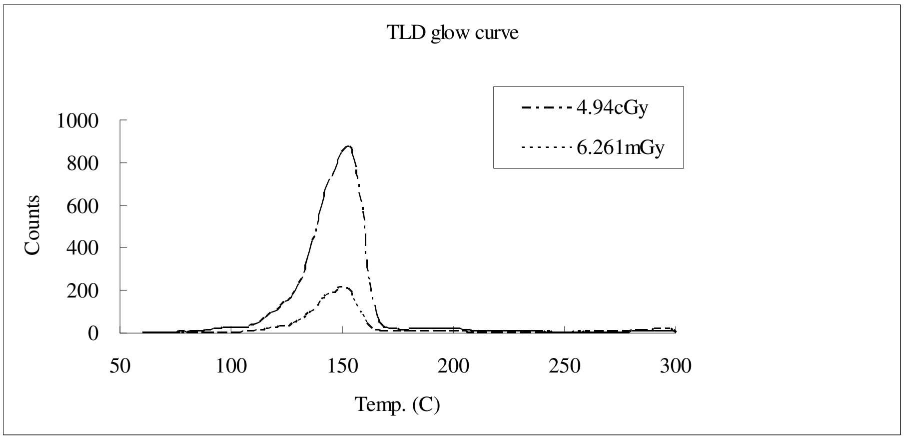

Fig. 4(B)

Fig.5 The cross interaction between parameters for various cases, (A) initial temp. *vs.* heating rate, (B)initial temp. *vs.* max. temp., and (C) heating rate *vs.* max. temp. of the TLD readout in this work.

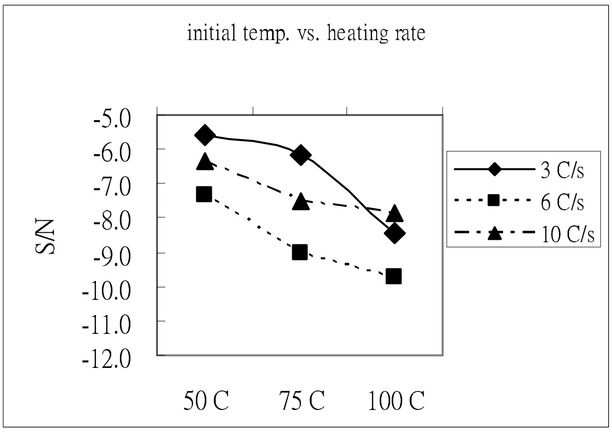

Fig. 5(A)

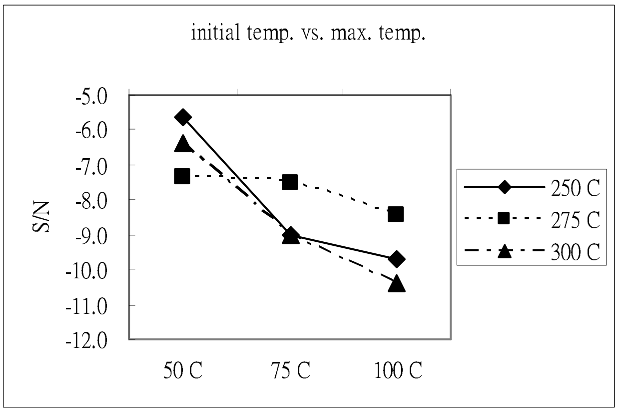

Fig. 5(B)

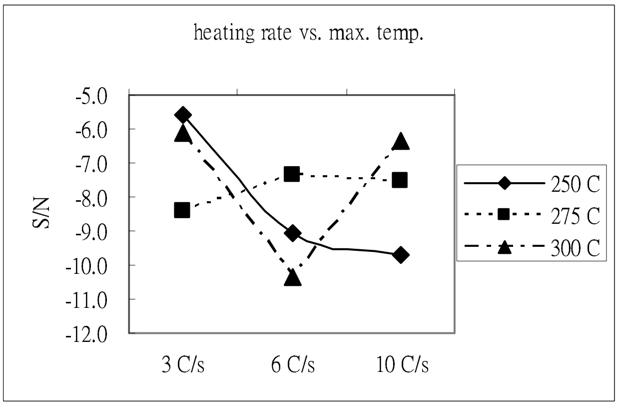

Fig. 5(C)

Table 1: Standard orthogonal arrays of nine different groups following Taguchi's suggestion. The numbers in each column indicate that the various concentrations or layouts considered for the specific parameters A-D.

Exp	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 2. Orthogonal arrays of various groups following Taguchi's suggestion.

Sampling No. (℃)	Initial heating temp. (℃/s)	Preheat time (min.)	Maximum temp. (℃)
1	50	3	5
2	50	6	10
3	50	10	20
4	75	3	10
5	75	6	20
6	75	10	5
7	100	3	20
8	100	6	5
9	100	10	10

Table 3: The original three TLD readings under various radiotherapy beam doses (50cGy, 100cGy and 150cGy) for nine groups of randomly assigned TLDs.

Group No.	50cGy			100cGy			150cGy		
	Tri 1	Tri 2	Tri 3	Tri 1	Tri 2	Tri 3	Tri 1	Tri 2	Tri 3
1	199072	197507	200397	409488	410839	412695	625324	626920	633624
2	198049	198542	198696	410999	410986	409468	631593	634242	630781
3	200258	196796	195962	416059	402969	406680	637541	617203	625201

4	194709	191662	193183	405932	400922	408983	622674	609389	615132
5	194808	196712	196805	403236	403465	401517	630079	627458	624645
6	197938	195863	198238	420800	413200	419364	637991	625679	644115
7	197246	191344	190391	424208	417747	415141	637712	627089	614641
8	195406	200989	199260	429084	441483	430541	645741	667436	666007
9	195047	196366	196486	423038	423813	424793	646665	646205	644032

Table 4: The analyzed result of the TLD readout under various radiotherapy beam doses (50cGy, 100cGy and 150cGy) for nine groups. The β is exactly gradient of the given dose as a function of TLD readout.

Group No.	Dose(cGy)			β	S	S/N (η)
	50	100	150			
1	198992	411008	628622	4152.7	7923	-5.6
2	198429	410485	632205	4165.7	9700	-7.3
3	197672	408570	626648	4135.4	8592	-6.4
4	193185	405279	615732	4072.8	8260	-6.1
5	196108	402739	627394	4119.7	11658	-9.0
6	197346	417788	635929	4201.0	10002	-7.5
7	192994	419032	626480	4157.9	10962	-8.4
8	198552	433702	659728	4350.2	14369	-10.4
9	195967	423881	645634	4258.0	13009	-9.7

Table 5: Comparison between previous setting and optimizal recommendation of System TLD readout

TLD readout parameter	Previous setting	Optimized recomm.
[*A*] initial temp.	100 ℃	50 ℃
[*B*] heating rate	6 ℃/*s*	3 ℃/*s*
[*C*] preheat time	5 *min.*	5 *min.*
[*D*] maximum temp.	300 ℃	250 ℃
S/N; η	-10.4 Db	-5.6 dB
cumulative error %	3.40%	1.74%

Table 6: Table of ANOVA and F-test for dynamic TLD readout system. The

confidence level was treated as significant if the percentage over 95%.

TLD readout parameter	sum of squares (S_A)	degree of freedom (f_A)	variance (V_A)	F_{A0}	Confidence Level
[*A*] initial temp.	16.72	2	8.3618	412.0	100%
[*B*] heating rate	8.42	2	4.2123	207.6	100%
[*C*] preheat time	0.10	2	0.0497	2.4	88.5%
[*D*] maximum temp.	0.37	2	0.1827	9.0	99.8 %
Total	25.61				

Table 7. Dimension, physical properties and body mass index (BMI) of Rando, SDM phantoms

Phantom	Rando	SDM	SDM	SDM
Weight (kg) (design)	70	50	70	90
Height (cm)	94.5	84	93	112
Weight (kg)[1]	34.5	31.5	44.1	57
BMI	22.2	21.6	22.2	27.8
Slices	35	31	31	31
cm /slices	2.5	2.7	3.0	3.6