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The Dose Over-response of the Markus Chamber in Build-up Region

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Tele-cobalt machines are widely used in radiotherapy treatment units in developing countries, which have a Markus chamber to measure surface and build-up doses without applying the over-response correction factor (ξ), therefore, the aim of this study is to introduce the formulas for predicting the ξ of the Markus for ^{60}Co beam in the present and previous studies. The percentage depth dose in build-up region was measured by a Markus, which was irradiated by a ^{60}Co beam. Irradiations were performed in solid water equivalent phantom at various depths and fields. The results showed that the percent over-response of *Gerbi and Khan* **()**values were higher than that for *Rawlinson* () for both chamber models at surface of phantom and reverse at all depth beyond surface, additionally, the measurements of (**%ξ**)were larger than that predicating for both formulas. Surface dose measurement is one of the most challenging issues for clinical dosimetry in radiotherapy. Accurate knowledge of surface and build-up region doses is very important. Therefore, this study recommends using the extrapolation chambers for measuring surface and build-up doses accurately. Although, these chambers are impractical because of very laborious and time-consuming procedures, so, this study also recommends using any formula of them to determine the dose over-response of Markus in build-up. These formulas can be easily implemented and allow the clinician and medical physicist to assess the accurate surface dose of patient. The percentage surface doses show a strong correlation to the structure of ionization chamber to minimize the over-response of chamber.

Keywords: Dose over-response of Markus chamber; Correction of percentage depth dose in build-up region, Cobalt-60.

Introduction

The most accurate instruments for measuring dose at the surface and in build-up region were the extrapolation parallel plate ionization chambers (PPICs), which are expensive, and few institutions have these instruments at their hospital. Furthermore, they are very laborious and time-consuming to utilize, in practice. As a result, the PPICs with fixed plate separation are commonly used for this purpose [1]-[5]. Several authors have reported the increased ionization in PPICs with fixed plate separation air cavity compared with the extrapolation PPIC measurements and they have re-emphasized that the inaccuracies in the measurement of dose in build-up region when using PPICs with fixed plate separation. They have studied the source of this over-response in megavoltage beams and have presented that, it is dependent on the construction and physical characteristics of the PPIC [1]-[5]. Nevertheless, the PPICs with fixed plate separation require correction, however, the first one that introduces a correction factor **ξ** was *Velkley et al.* [1]. They suggested the correction factors derived from cylindrical extrapolation PPIC measurements and investigated the relationship between the correction factor and plate separation at different photon energies and depths. They formulated an empirical correction to the over-response of the PPIC with fixed plate separation in which electrode separation was considered as the major chamber geometrical factor affecting the measurement accuracy. The correction factor **ξ** represented in the form of

$$P'(d)=P(d)-\xi(E,d/d_{max})\times L=P(d)-\xi_V(\%) \text{--------}\rightarrow[1]$$

where ***L*** is plate separation in mm, ***d*** is depth to the front surface of the chamber, ***damx*** is maximum depth dose, ***E*** is the nominal maximum energy

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of photon spectrum, ***E*** is a correction factor, ***P***is corrected percentage build-up and ***P*** is the percentage build-up obtained with the chamber with plate separation mm. ***L*** The correction factor ***E*** decreases with increasing photon energy and increasing depth for fixed photon energy. For their extrapolation PPIC design, they found to be approximately 3.72%/mm, 3%/mm, 1.6%/mm, and 1%/mm for 1.25, 4, 8, and 25 MV beams, respectively. Unfortunately, the proximity of the side walls was not considered, and this caused incorrect results under certain conditions [1].

On the other hand, *Gerbi and khan* [3] improved the previous correction method [1] by including the influence of the collector edge-sidewall distance to the chamber and the dose-response of the chamber for different detector types at various beam energies and depths. By comparing the readings of the various detectors with the reading of an extrapolation PPIC, the correction formula was given by:

$$P'(d,E)=P(d,E)-\xi(0,E)Le^{-\alpha(d/d_{max})}(\%)\text{------------------}\rightarrow [2]$$

$$\xi(0,E)=(-1.666+1.982IR)\times(C-15.8)(\%/mm)\text{-------}\rightarrow [3]$$

Substituting equation [3] into equation [2], we get:

$$P'(d,E)=P(d,E)-[(-1.666+1.982IR)(C-15.8)Le^{-\alpha(d/(d(max))}] =P(d,E)-\xi_{GK}\ (\%)\rightarrow[4]$$

where ***a*** is a constant with a value of **5.5**, ***C*** is the sidewall collector distance and is the ionization ratio. *IR* is the ratio of ionization measurements made in water for 10×10 cm^2 field size at depths of 20 and 10 cm with a constant source-chamber distance of 80 cm [3], [5], [6]. Under certain chamber geometry, the correction formula of Gerbi and khan gave inaccurate results due to they didn't take care the size of the collector electrode into account.

Mellenberg [4] compared the response of the Markus PPIC to that of an extrapolation PPIC in the build-up region of megavoltage x-ray beams and generated tables of correction factors to account for the 'over-response' of the Markus PPIC. The over-response is due to the small guard ring width in the Markus design [3].

Rawlinson et al. [5] reevaluated *Velkley's* correction factor for commercially available PPICs with fixed plate separation and pointed out that *Velkley's* formula needs to be modified to include the influence of the chamber geometry and density of wall material. They provided an improved formula:

$$P'(d,E)=P(d,E,G)-\xi(d,E,G)(\%)\text{---------------}\rightarrow[5]$$

$$\xi(d,E,G)=\xi(0,E,G)e^{-\alpha(d/d_{max})}(\%)\text{--------------}\rightarrow[6]$$

$$\xi(0,E,G)=C(E)\left(\frac{L}{W}\right)\left(\frac{P}{1.17}\right)^{0.5}\text{-----------------}\rightarrow[7]$$

Substituting equations [6 & 7] into the basic equation [5], we find:

$$P'(d,E)=P(d,E,G)-C(E)\left(\frac{L}{W}\right)\left(\frac{P}{1.17}\right)^{0.5}e^{-\alpha(d/d_{max})}=P(d,E,G)-\xi_R\ (\%)\rightarrow[8]$$

where, ***G*** is the geometry, ***L*** is the electrode separation,***W*** is the inner diameter of a wall,***P*** is the density of wall material (g/cm^3), ***α*** is a constant with value 4.0±0.8, and C(E)=43%,27% and 15% for 1.25,6 and 18 MV, respectively .

The aim of this study is to introduce the formulas for predicting the over-response of Markus PPIC models 30-329 and 23343 for ^{60}Co γ-ray beam in the present and previous studies and compare their dose over-response in the build-up region. Additionally, to measure the surface dose with various field sizes.

Methods and Materials

Markus ionization chamber

Markus is a PPIC (Model TW 23343). It is composed of a small guard ring that has 0.2 mm wide, 2 mm electrode separation, and 0.057 cm^2 collecting volume. The electrode diameter has a 5.3 mm, 6 mm wall diameter, and 0.35 mm the collector sidewall with a density of 1.19 g/cm^3 [7], [8].

Measurements setup

In this study, a Markus chamber and a Farmer 2570/1 electrometer from Net Technology were used to evaluating surface and build-up doses. It was connected via low noise triaxial cable to electrometer with applied bias voltage 300 V. It was embedded in 30×30 cm2 slabs of Perspex phantom and was used to measure ionization charge on the central axis in the build-up region. Phantom material of varying thickness was taken from below the chamber and placed above the chamber to increase the depth of measurement. Therefore, it was kept at a constant source to surface distance (SSD) for all measurements. A minimum of 18 cm of backscatter thicknesses was used to ensure full phantom scatter equilibrium. The measurements were performed using a Theratron 780E ^{60}Co beam with field sizes of 5×5 up to 25×25 cm^2 at a fixed 80 cm SSD and different depths from surface to 0.9 cm. Beam time on was1min for each measurement. A total of six readings by electrometer for two bias voltages (± 300 V) were recorded and averaged for each depth and field size configuration. The polarity effect correction factor was considered for Markus PPIC measurements.

$$Q' = \frac{(Q_p + Q_n)}{2} \longrightarrow [1]$$

where Q is the polarity effect, Qp is positive polarity and Qn is negative polarity.

The percentage depth doses (%DDs) were obtained by normalizing the dose at the measured depths to the dose at $\boldsymbol{d_{max}}$. In this study, the dose over-response of Markus PPIC was calculated using the formulas by *Velkely et al.* [1], *and Khan* [3], and *Rowlinson et al.* [5] to compare calculated and measured dose over-response reported by their studies (ξV, ξGK, and ξR). . Over-responsefactors were applied to the Markus PPIC readings using their formulas to evaluate surface and build-up doses.

Results

Measurements of dose over-response

Figure 1.a indicates the %DD curves for 10×10 cm^2 field size that were measured using Markus model 23343. In this study author using Markus (AM), and Velkely et al. [1] using extrapolation chamber (VE) in their study. As can be seen from Figure 1.a the %DD for Markus was higher than that of extrapolation PPIC. Therefore, the percentage depth dose differences (%DDD) between both chambers (VE&AM), which is called the dose over-response of the chamber, was 21.75% at the surface. Moreover, the graph's in Gerbi and Khan [3] study (GK), which showed the difference, in percent, between the measured %DD in build-up region using Markus PPIC model 30-329 versus that measured with the extrapolation PPIC was plotted in Figure 1.b. Therefore, the %DDD between both chambers was 18.2% at the surface and decreased with increasing depth. For comparing, the %DDD in Figure 1.a. was plotted with that in Figure 1.b.

Predictions of dose over-response

Gerbi and Khan [3] and Rowlinson et al. [5] used Markus PPIC model 30-329 with a 5.4 mm electrode diameter, a 5.7 mm wall diameter, and a 1.17 g/cm^3 side wall density to evaluate its over-response.

The percentage dose over-response (%ξ) as a function of depth, which predicted from formulations developed by velkely et al. [1], Gerbi and Khan [3] and Rawlinson et al. [5] that mentioned before, are illustrated in Figure 2. The value of the %ξV [1] at surface was 7.4%. As can be seen from Figure 2 the %ξV was the smallest value compared with the %ξGK and the %ξR, also the %ξR was smaller than that of the %ξGK. Additionally, the %ξGK and the %ξR for Markus 23343 in this study, are presented in Figure 2, which reveals that the %ξ is dependent on depths.

Percentage depth dose in build-up region

Figure 3.a shows the %DDs without and with correction factors for 10×10 cm^2 field size. The values ofthe % ξGk , %ξR , and %Δξ (%Δξ = %ξR - %ξGK) at the surface for both models of Markus PPIC are summarized in Table 1.Figure 3.b graphically represents the %ξGK , % ξR, , and % Δξ and curves for both models of Markus PPIC (30-329& 23343). These values were slightly higher for Markus model 30-329 than that model 23343. On the surface of phantom, , the %ξGK values were slightly higher than that the %ξR and at all depth beyond the surface, the values of the %ξR were somewhat higher than thatthe %ξGK for both models.

Surface dose measurements

The percentage surface dose (%SD) curves as a function of field size for the present and previous studies are presented in Figure 4. The black axis refers to the %SD obtained with the chamber and the blue axis refers to corrected %SD. The results of present and previous studies [3] indicate that the %SDs for Markus 30-329 and 23343 were approximately as same as for each field sizes. Accordingly, the variations (M_{23343}-M_{30-329}) in %SD for both Models were 0.57%, 0.35%, 0.11% and -1.58% for 5×5 ,10×10, 15×15 and 25×25 cm^2 field sizes, respectively. The %SD results using extrapolation PPIC were less than that of both Markus PPIC models, so, the percentage surface dose differences (%SDDs) were 18.2% and 18.55% for Markus 30-329 and 23343, respectively. The solid right triangle and stare indicate %SDs measured using extrapolation PPIC in *Velkely's* and *Rawlinson's* studies, respectively for 10×10 cm^2 field. The errors were determined from repeated measurements and represent the root –mean- square deviation in the measurements of about ±0.11%.

Discussion

Gerbi and Khan [3] and *Rawlinson et al*. [5] measured and predicted the **%ξ** of Markus PPIC model 30-329 (see **Table 1**) and found that the **%ξ**

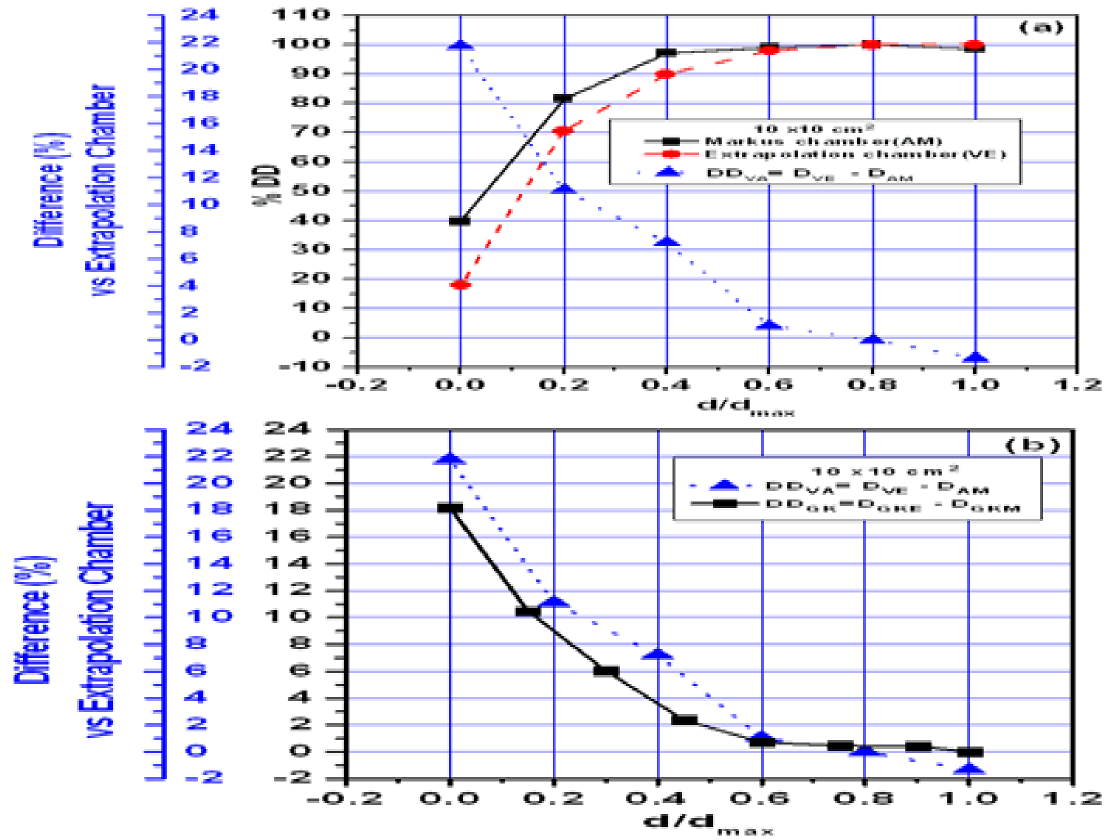

Fig. 1. Percent over-response of (a) Markus model 23343 and (b) Markus model 30-329.

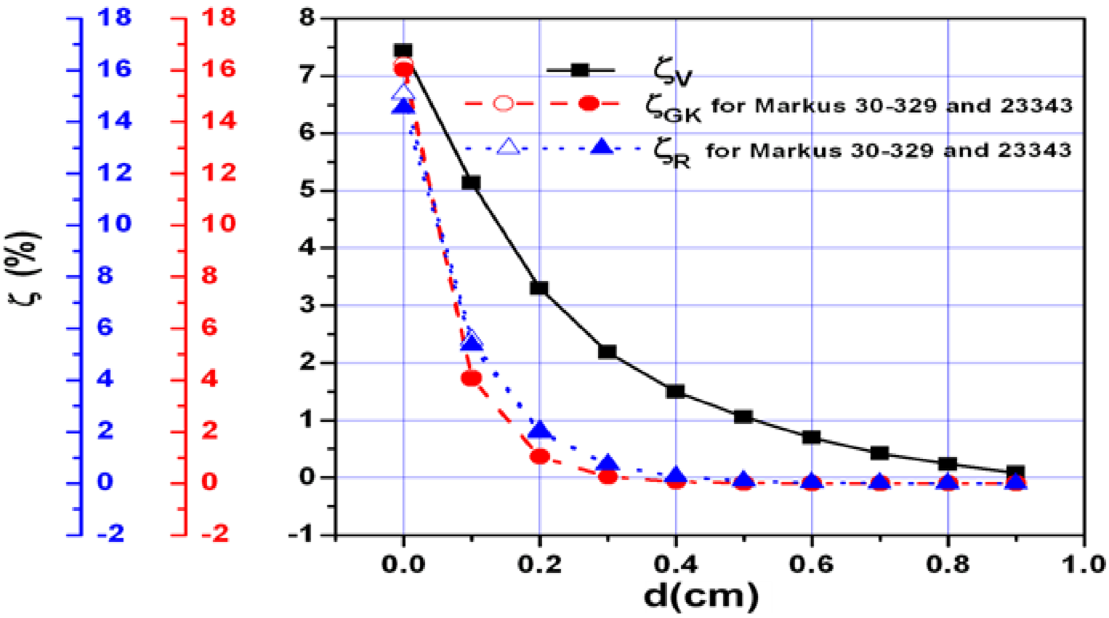

Fig. 2. The %ξ as a function of depth.

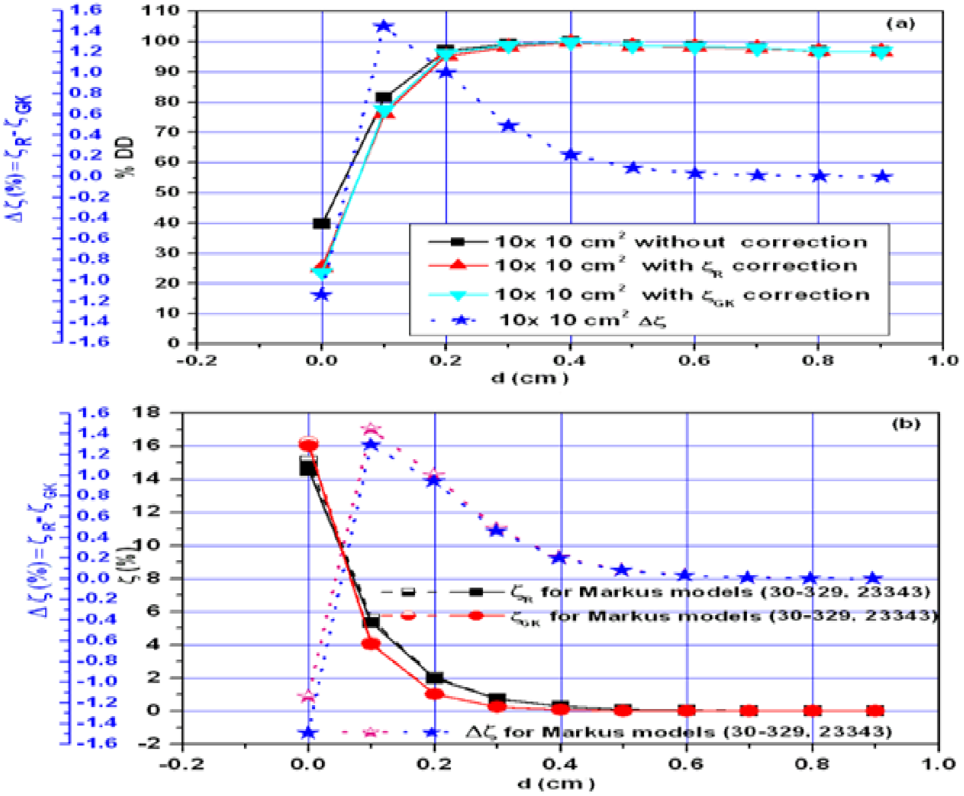

Fig. 3. (a) The %DD curves versus depth and (b) the values of the%ξGK and %ξR for Markus models 30-329 and 23343.

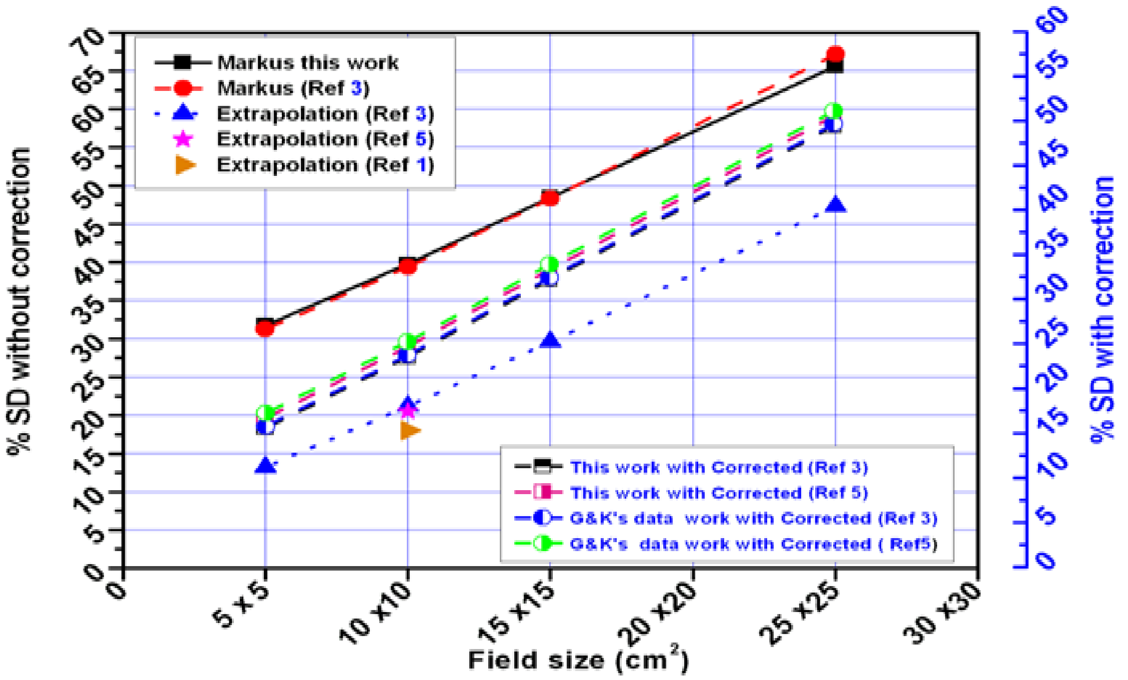

Fig. 4. Percentage surface dose versus field size for the present and previous studies.

is independent on field size, but it is dependent on depths.

The average over-response that measured for Markus PPIC models 30-329 and 23343 were 18.95% and 19.85%, respectively, however, the %Δξ between them was -0.9%, which refer to some following things; Geometrical chambers, delivery beams, phantoms, and measurements set up.

As can be seen from Table 1 the measurements of %ξ were larger than that predicating, so, this study recommends using extrapolation PPICs for measuring surface and build-up doses accurately as like mention in Nilsson and Montelius study's [2].

Nevertheless, *Gerbi and khan* [3] and *Rawlinson et al.* [5] developed the correction formula that was given previously, even so, the author view that the Markus PPIC still needs correction.

It may conclude the dose over-response strongly depends on the design of the geometrical structure of Markus PPIC. So, this study also recommends using any formulas of them to determine the dose over-response of Markus PPIC in the build-up region for the ^{60}Co beam.

The highest variation of the %SD is approximately 3.2% (see Table 1), even though, the previous studies [1] , [3] , [5] used different models of extrapolation PPIC and delivery beams.

Conclusion

Surface dose measurement is one of the most challenging issues for clinical dosimetry in radiotherapy. Accurate knowledge of surface and build-up region doses is very important. These formulas [3], [5] confirmed the limitations of a surface dose evaluation based on the dose over-response to predict the corrected surface dose. These formulas can be easily implemented and allow the clinician and medical physicist to assess the accurate surface dose of the patient.

The results showed that the measurement of percent over-response (**%ξ**) was higher than that predicating for both formulas. This study recommends using the extrapolation PPICs for measuring surface and build-up doses accurately.

TABLE 1. The comparing results of %ξ and %SD for present and previous studies for a 10×10 cm^2 field at the surface phantom.

Authors	Machines	PPICs	%ξ measured	%ξ predicted	%Δξ	%SD
Velkely et al.[1]	Theratron-80	Extrapolation				18%
Gerbi and Khan [3]	Eldorado 8	Markus 30-329	18.7%			39.4%
		Extrapolation 30-360				21.2%
Rawlinson et al. [5]	Theratron-780	Markus 30-329	19.2%	16.6%		39.7%
		Extrapolation				20.5%
present and previous [1] studies	Theratron-780	Markus 23343	21.75%		-0.9 -1.14 -1.49	39.75%
present and previous [3] studies			18.55%	16.23%^{a} 16.02%^{b}		
present and previous [5] studies			19.25%	15.09%^{a} 14.53%^{b}		

^{a}Markus model 30-329 and ^{b}Markus model 23343.

Although, extrapolation PPICs are impractical because of very laborious and time-consuming procedures, so, this study also recommends using any formula of them to apply correction of the dose over-response in build-up region. As a result, the %SDs showing a strong correlation to the structure of the ionization chamber to minimize the over-response of the chamber.

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جرعة الاستجابة-الزائدة لغرفة ماركوس في منطقة النمو

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تستخدم أجهزة تيليكوبلت على نطاق واسع في وحدات العلاج الإشعاعي في البلدان النامية، بعضاُ من تلك الوحدات تمتلك غرفة تأين ذات الواح متوازية تسمي بماركوس و التي تستخدم لقياس جرعات السطح ومنطقة النمو دون تطبيق عامل تصحيح جرعة الاستجابة الزائدة(ξ). و عليه، فإن الهدف من هذه الدراسة هو التركيز علي عوامل تصحيح جرعة الاستجابة الزائدة لغرفة ماركوس في أشعة γ التي ذكرت في الدراسات السابقة. لقد تم قياس جرعة العمق المئوية (DD٪) في منطقة النمو بواسطة غرفة ماركوس، والذي تم تشعيعها بواسطة أشعة الكوبالت ٦٠ . وأجريت عمليات التشعيع في فانتوم المياه الافتراضية على أعماق و حقول علاجية مختلفة. و قد أظهرت النتائج أن النسبة المئوية لجرعة الاستجابة الزائدة لقيم *Gerbi and Khan (KG ξ ٪)* كانت أعلى من قيم *Rawlinson* (ξR٪) لكلا من موديلين غرفة ماركوس على سطح الفانتوم والعكس في كل عمق وراء السطح، بالإضافة إلى ذلك، كانت قياسات ξ٪ أكبر من تلك المتنبئ بها في كلا الصيغتين. اثبتت النتائج أن قياس الجرعة السطحية هي واحدة من أكثر القضايا تحديا لقياس الجرعات السريرية في العلاج الإشعاعي. لذا فان المعرفة الدقيقة لجرعات السطح ومنطقة النمو مهمة جدا. وعليه، هذه الدراسة توصى باستخدام غرف الاكسترابوليشن " extrapolation" لقياس جرعات السطح ومنطقة النمو بدقة. على الرغم من أن غرف الاكسترابوليشن غير عملية بسبب أن إجراءات اخذ البيانات شاقة للغاية وتستغرق وقتا طويلا، وعليه، أوصت هذه الدراسة أيضا باستخدام أي صيغة من تلك الصيغ لتحديد الجرعة الزائدة لغرفة ماركوس في منطقة النمو. يمكن تنفيذ هذه الصيغ بسهولة وتسمح للطبيب والفيزيائي الطبي بتقييم الجرعة السطحية الدقيقة للمريض.علماً بان النسبة المئوية للجرعات السطحية تظهر ارتباطا قويا بتركيب غرفة التأين لتقليل الاستجابة الزائدة للغرفة.