Research Article

Skin Dosimetry in Breast Teletherapy on an Anthropomorphic and Anthropometric Phantom

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Abstract

This paper addresses the breast Teletherapy Dosimetry. The goal is to evaluate and compare absorbed doses in equivalent skin tissue, TE-skin, of an anthropomorphic and anthropometric breast phantom submitted to breast radiotherapy. The methodology involved the reproduction of a set of tomographic images of the phantom, the elaboration of conformational radiotherapy planning and the synthetic breast irradiation by parallel opposed fields with prescribed dose of 1.80 Gy to the Target Volume (PTV). Radiochromic films EBT2 were selected as dosimeters. Two independent calibration processes of films with solid water Gammex 457 plates and water filled box were produced. Curves of Optical Density (OD) versus absorbed dose were produced. Dosimeters were positioned in the external region of the breast phantom in contact with TE-skin. The irradiation process was prepared in duplicate to check the reproducibility of the technique. The radiochromic films were scanned and their response in RGB (Red, Green, Blue) analyzed by the Image software. The optical density was obtained and converted to absorbed dose based on the calibration curves. Thus, the spatial distribution of the absorbed dose in the skin was reproduced. The absorbed doses measured on the radiochromic films in TE-skin showed doses values in the upper and lower quadrants in the range of 54%, 72% and 68% of prescribed dose. The values are mean 64% of the precribed dose. As conclusion, the depth absorbed dose measured in solid water plates or water box reproduce values with no significant statistical differences for both calibration processes of the radiochromic films. It was observed that the skin received absorbed doses ranging from 50% to 78% of the prescribed dose in the two parallel opposed irradiation fields.

Keywords: Skin Dosimetry; Breast Teletherapy; Phantom and radiochromic films

Introduction

The breast neoplasm is the most frequently diagnosed cancer in women around the world representing about 25% of all new cancer cases [1]. According to Consensus Document between the Brazilian Medical Association and the Federal Medical Council [2,3], the therapeutic modalities often used are surgery and radiotherapy for localized tumor; while, chemotherapy and endocrine therapy for systemic treatment. The main modalities used in radiotherapy are Teletherapy, provided by Cobalt therapy or linear accelerator 4-6 MV, and brachytherapy based on Low-Dose-Rate (LDR) implants of iridium-192 wires or on High-Dose-Rate (HDR) after loading Ir-192 brachytherapy [4,5].

Phantoms are physical objects or mathematical models used to reproduce the characteristics of the radiation absorption and scattering in body or body part. They are generally used to simulate the ionizing radiation transport and the dosimetry [6]. Dosimetry is the determination of absorbed dose at one point of a material medium exposed to ionizing particles [7].

Radiochromic films are used for radiation Dosimetry since 1960s. The recent improvements in technology associated with the production of these films made their use increasingly popular.

The main advantages of radiochromic films include photon tissue equivalence, high spatial resolution, linearity with absorbed dose, low energy dependency, insensitivity to visible light and no need for revelation, made them suitable for applications in quality control procedures in radiotherapy [8,9]. This work is justified by the need of measuring skin dose in patients submitted to Teletherapy. It is known that there is now a greater number of new Technologies and Planning Software's (TPS), whose evaluation requires experimental inter comparison of the recommended prescribed doses in TPS to the absorbed doses received by the patients. It is also known that the harmful effects on the skin are still identified today in the breast radiotherapy; and, as the incidence of breast cancer has increased, it is necessary provide measurements of the skin dose, to assess changes in the current irradiation protocols. To do so, technology of the radio chromic films is a suitable tool to measure and validate the skin dose in breast radiotherapy.

Materials and Methods

Phantoms, image generation and references marks

Thorax and breast phantoms, developed by the research group NRI /UFMG [10,11], were used as a basis for dosimetric studies. The breast phantom consists of three-Tissue Equivalent (TE's): glandular, adipose and skin made of human elemental composition defined by

ICRU-44 [12]. The images generation by Computed Tomography (CT), a GE Healthcare Hispeed CT model was used. A radio transparent support was used to hold the thorax phantom, keeping it in the same position during the CT images generation and during the irradiation of the breast phantom. Cross marks were set in the thorax phantom together with radiopaque fiducials to computer-assisted positioning in establishing the isocenter.

Conformal radiotherapy planning (TPS)

The conformal radiotherapy planning was performed using a series of CT images of the thorax phantom imported by the SOMAVISION program. The setup data of the radiotherapy planning were exported to CADPLAN program for generating the isodose curves. The employed method for the tissue in homogeneity correction was the modified-Batho [13], which adjusts the absorbed dose calculations through the differences in the attenuation coefficients that the primary beam undergoes in tissue compared to water. The simulated planning was based on a typical prescription for breast cancer radiotherapy with a total prescribed dose of 50.4 Gy in 28 fractions of 1.8 Gy per day, isocentric technique and filter type-15. The total calculation of the Monitor Units (MU) for the internal tangent field was 126 and 132 MU for the external tangent field; fields´ size of 7.5 cm in x-axis and 14 cm on y-axis. Angles of the collimator and gantry were 14º and 297º for the internal tangent field, respectively. For the external tangent field, both were 346º and 101º, respectively. Source-Surface Distance (SSD) was 91.4 cm and 94.1 cm for the internal and external tangential fields, respectively.

Positioning of radiochromic films and irradiation of the breast phantom

Three radiochromic films of type Gafchromic® EBT2 International Specialty Products (ISP) [14], 2.0 cm x 2.0 cm dimension, sealed with plastic for protection against external agents, were used in each irradiation. These were positioned in surface regions of the breast phantom to measure absorbed dose in the synthetic skin. The 1st radiochromic film was positioned between upper and lowerquadrants at 9 o'clock, the 2nd film in the lowerquadrant at 6 o'clock and the 3rd film between the upper and lowerquadrants at 3 o'clock in the skin TE, shown in Fig.1.Two irradiations of the breast phantom were performed in the linear accelerator 2100C of VARIAN MEDICAL SYSTEMS Company with 6 MV. The thorax phantom was positioned on a radio transparent support on the radiotherapy table such that the radiation beam focus was out of the support. The references marks in the synthetic skin were used for positioning the lasers, ensuring the reproducibility of the isocenter positioning in relation to the radiotherapy planning. The irradiation was performed in duplicate.

Calibration protocols - water phantom and solid water plates

The linear accelerator VARIAN 2100C was calibrated following the protocol TRS 398 [15] such that a MU corresponded to 0.01Gy at the depth of electronic equilibrium for a 10 cm x 10 cm field and a Source-Skin Distance (SSD) of 100 cm. For dosimeter´s calibration a water phantom with 30 cm³ and solid water Gammex 457 plates with 20 x 20 cm and 4 cm thick were used.

For water phantom calibration, six 3.0 cm x 3.0 cm sealed radiochromic films were fixed on a support in to the water phantom following the direction of the central ray of the irradiation field. The vertical depths of the film were: 1.5 cm; 3.5 cm; 7.5 cm; 11.5 cm; 15.5 cm and 19.5 cm from the surface of the water. The films were irradiated simultaneously, following the standard setup of the accelerator, assuming a SSD of 100 cm and a 10 cm x 10 cm field. In this configuration, 200 MU were applied, which represents an absorbed dose of 2.0 Gy at 1.5 cm depth for a field of 10 cm x 10 cm and SSD of 100 cm. The percentage dose profile - PDP to the depths of 1.5 cm; 3.5 cm; 7.5 cm; 11.5 cm; 15.5 cm and 19.5 cm were 100.0%; 92.4%; 76.0%; 61.3%; 48.9% and 39.5%, respectively. The multiplication of the MU by PDP values determined the absorbed dose in each film in their depths.

For calibration with solid water plates, ten 3.0 x 3.0 cm sealed radiochromic films were positioned in the center of the solid water plate at 4 cm depth, SSD of 100 cm and 10 cm x 10 cm field. Ten irradiations were performed for replacing each film, covering the dose domain of 0.25 Gy to 2.5 Gy, with an interval of 0.25 Gy.

Digitisation and reading of radiochromic films for calibration

The exposed radiochromic films from both calibration protocols were digitalised by transmission scanner, model Scan get HP G4050.The RGB color components in each image were splited on its components in the ImageJ program. The RGB value of each component was settled into a range from 0 to 255, in gray level, where 255 corresponds to white and zero corresponding to the absence of colour, black. The radiation absorbed by the radio chromic film was indicated by the degree of intensity of the Red (R) and Green (G) components.

The optical densities associated with the intensity of the R and G components generated from the RGB decomposed images were evaluated as follows:

$$OD = \log_{10} \frac{I_0}{I}, \tag{1}$$

where OD is the optical density of the film; I_0 represents the intensity of the R or G components in the non-irradiated film; and I represents the intensity of the R or G components intensity in the irradiated film. The standard deviation of the optical densities of sensitised and non-sensitised radiochromic films were evaluated as follows:

$$\sigma_{OD}(RGB) = \frac{1}{ln(10)} \sqrt{\frac{\sigma_I(RGB)^2 + \sigma_o^2}{m_I(RGB)^2 - m(FO)^2} + \frac{\sigma_n(RGB)^2 + \sigma_o^2}{m_n(RGB)^2 - m(FO)^2}} \tag{2}$$

where σ_{OD} is the standard deviation of the optical density obtained from the intensities of R, G or B components from the film; σ_I is the standard deviation of the averages of the R, G and B components of the irradiated film; σ_o is the standard deviation of a scanned opaque film; σ_n is the standard deviation of the averages of the R, G or B components of the non- irradiated film; m_I is the average of the R, G or B components of the irradiated film; m_n is the average of the R, G, or B components of the non-irradiated film; and $m(FO)$ is the average of the R, G, or B components of the opaque film.

A mathematical relationship between optical density and absorbed dose percentage or absorbed dose was obtained. A linear fit was prepared on the ORIGIN program [16]; adjusting the OD values

of the R component from the calibration´s films and the absorbed dose percentage or absorbed dose for each calibration method, provided by the expressions:

$$DP = b+a(OD) \qquad (3)$$

$$D = b'+a'(OD) \qquad (4)$$

in which DP represents the absorbed dose percent, D represents absorbed dose, b and b' the intercept of the straight line on the ordinate axis, a and a' the slope of the straight line, OD the optical density. We also performed the intensity´s readings of not-sensitised and sensitised films to identify the maximum value of R, B, and G components.

Dosimetry of the TE skin

After irradiation of the breast phantom, sensitized films were removed of their sealing and scanned in transmission scanner model HP Scanget G4050. The digitalized images were decomposed into their R, G, and B components through of the ImageJ program, saved on ASCII files. The R-component data were converted into the optical density applied to each pixel, according to equation (1). It preserved the spatial distribution of the absorbed dose. The standard deviation was calculated according to equation (2). The optical density values were converted to the absorbed dose percent or absorbed dose by equation (3) or (4), in intervals of 0.1 Gy and transformed into surface graphs. Absorbed doses in radiochromic films positioned over the synthetic skin were analyzed. Comparison between the two irradiation of the breast phantom and between the two calibration protocols was performed.

Results and Discussion

Radiation therapy planning

Figure 1 depicts an image of the breast phantom. Also, it is depicted the radiation therapy planning taken at the sagittal and axial plane. The 100% isodose values represented a prescribed dose of 1.8 Gy. The internal glandular doses were set superior to 100% up to 105%. The dose at skin is estimated on the TPS as 85% (Figure 1).

Calibrations with water phantom and solid water plates

According to the calibration performed with water phantom, the absorbed doses to the depths and respective PDP were: 2.0 Gy at 1.5 cm depth corresponding to 100% PDP; 1.85 Gy at 3.5 cm depth corresponding to 92.4% PDP; 1.52 Gy at 7.5 cm depth corresponding to 76.0% PDP; 1.23 Gy at 11.5 cm depth corresponding to 61.3% PDP; 0.98 Gy at 15.5 cm depth corresponding to 48.9% PDP and 0.79 Gy at 19.5 depth corresponding to 39.5% PDP.
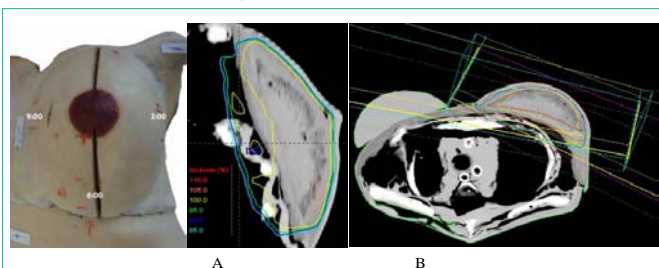

Figure 1(A): The breast phantom, pointing out the orientation position in which each film was placed on the skin TE; and, (**B**) the therapy planning system at the breast phantom.
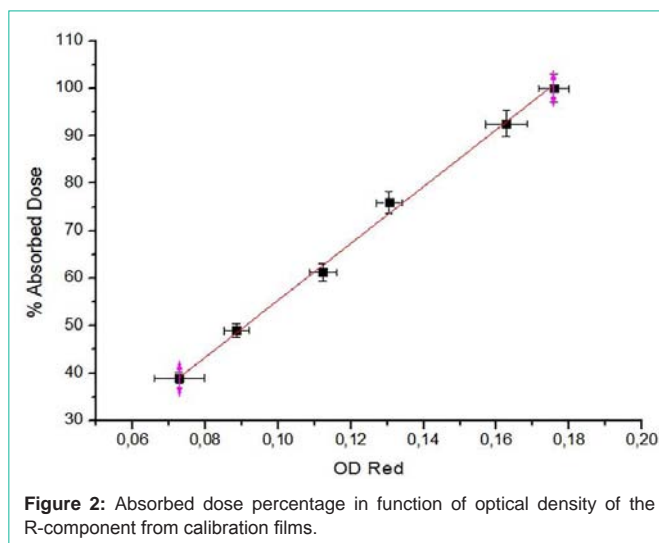

Figure 2: Absorbed dose percentage in function of optical density of the R-component from calibration films.

For calibration performed with solid water plates, the absorbed doses for 10 radiochromic films were measured at the constant depth of 4 cm corresponding to 90.4% of the PDP, with the following MU: of 2.26 Gy; 2.03 Gy; 1.80 Gy; 1.58 Gy; 1.35 Gy; 1.13 Gy; 0.90 Gy; 0.67Gy; 0.45 Gy; 0.22Gy.

Calibration data analysis with of water phantom

Figure 2 shows the straight line correlating the absorbed dose percentage in function of optical density generated in the R component. It is observed that the absorbed dose percentage increases as the R optical density is increased. The standard deviation of the optical density, evaluated by Eq.2, was identified as well as the uncertainties in the measurement of the PDP. The quality of the linear regression was evaluated with 0.996 (R^2). The uncertainties in the dose were in accordance with the radiotherapy planning, which was less than 2.5% (Figure 2).

Calibration data analysis with solid-water plates

Figures 3A and B shows the calibration straight line of dose (Gy) in function of optical density generated in the R component. For best adjustment of the calibration, two linear fits were performed in the lower dose interval of 0.22 Gy to 1.35 Gy and then in higher dose interval of 1.35 Gy to 2.26 Gy.

It can be also observe that the dose increases as the optical density increased. The standard deviation of the optical density evaluated by Eq.2 was identified as well as the uncertainties in the measurement of the PDP. The quality was evaluated with linear regression of the 0.995 (R^2) to low doses (Figure 3A) and 0.988 (R^2) for high doses (Figure 3B). The uncertainties presented in dosage were in accordance with the radiotherapy planning, which was less than 2.5% Figure 3A and B.

Correlation dose versus optical density

The optical density values were converted into absorbed dose percentage values in depth for calibration process with water phantom, satisfying the linear relationship such that:

$$DP = -4.50\ (\pm1.97)+598.90\ (\pm18.77).\ OD \qquad (5)$$

In which DP represents the absorbed dose percentage and OD represents the optical density, with quality of the regression of 0.996
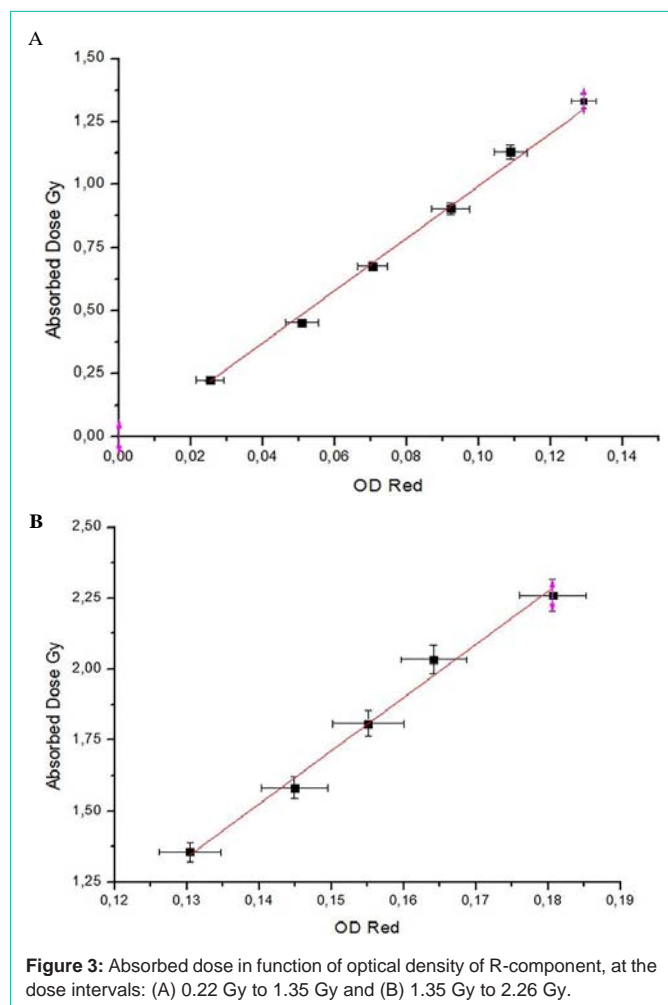
A

B

Figure 3: Absorbed dose in function of optical density of R-component, at the dose intervals: (A) 0.22 Gy to 1.35 Gy and (B) 1.35 Gy to 2.26 Gy.

(R^2). For calibration with solid water plates, optical density values were converted into absorbed dose satisfying the linear relationship for low doses of 0.22 Gy to 1.35 Gy, as follow:

$$D = -4.50 (\pm 0.83) + 1043.27 (\pm 17.09). OD \quad (6)$$

in which D represent the absorbed dose, with a quality of the regression of 0.995 (R^2). The linear relationship for doses of 1.35 Gy to 2.26 Gy is:

$$D = -109.94 (\pm 17.54) + 1874.66 (\pm 117.03). OD \quad (7)$$

with quality of the regression of 0.988 (R^2).

Dosimetry of radiochromic films in TE skin

Figure 4 illustrates the absorbed dose distribution in 1st radiochromic films (9 o´clock), 2nd (6 o´clock) and 3rd (3 o´clock), positioned in contact with TE skin of breast phantom, using the calibration method with water phantom Figure 4.

The estimated absorbed dose at the skin TE was in the interval of 1.0 Gy to 1.4 Gy, with mean and standard deviation of 1.2 ± 0.1 Gy, corresponding to 68.5 ± 6.4 % of the prescribed dose of 1.8 Gy. The average doses by the films 9, 6 and 3 o´clock were respectively: 1.1 ± 0.1 Gy; 1.3 ± 0.1 Gy and 1.3 ± 0.2 Gy.

Figure 5 illustrates the absorbed dose distribution in radiochromic
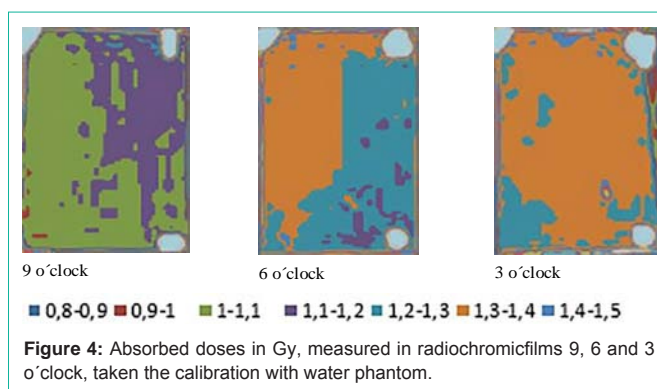

Figure 4: Absorbed doses in Gy, measured in radiochromicfilms 9, 6 and 3 o´clock, taken the calibration with water phantom.
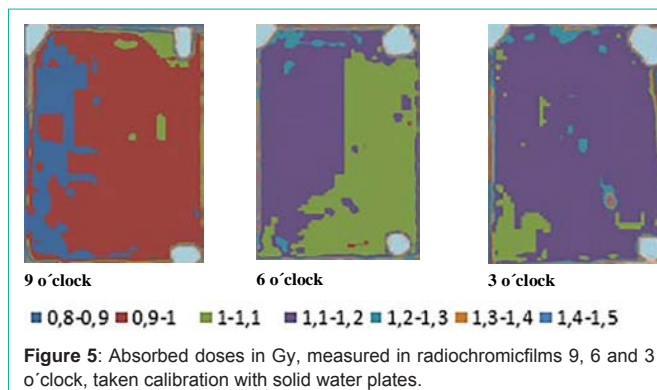

Figure 5: Absorbed doses in Gy, measured in radiochromicfilms 9, 6 and 3 o´clock, taken calibration with solid water plates.

films 9, 6 and 3 o´clock, positioned in contact with skin TE of breast phantom, using the calibration method with solid-water plates (Figure 5).

The dose estimated at the skin TE was in the range of 0.8 Gy to 1.3 Gy, with mean and standard deviation of 1.1 ± 0.2 Gy, corresponding to 59.3 ± 8.5% of the prescribed dose of 1.8 Gy. The average doses by the films 9, 6 and 3 o´clock were respectively: 0.9 ± 0.1 Gy; 1.1 ± 0.1 Gy and 1.2 ± 0.1 Gy.

It can be observed in Figures 4 and 5, that radiochromic films 6 and 3 o´clock, received higher doses than radiochromic film9 o´clock The results for the radiochromic film 3 o´clock may be due to the higher values of MU applied for the external tangent field of 132 MU than an internal tangent field of 126 MU. For radiochromic film 6 o´clock this result may be due to the surface proximity in relation a hot glandular region verified and performed in radiotherapy planning system.

The mean absorbed doses in the TE skin for two irradiations for each of the three positions were: 1.0 ± 0.1 Gy for 9 o´clock, which represent 56 ± 7.8% of the prescribed dose; 1.25 ± 0.1 Gy for 6 o´clock, which represent 69 ± 3.9% of the prescribed dose, and 1.2 ± 0.1 Gy for 3 o´clock, which represent 67 ± 7.8% of the prescribed dose of 1.8 Gy. The mean overall mean skin absorbed dose was 1.2 ± 0,1Gy which represents a mean of 64 ± 7.3% of the prescribed dose.

The dose builds up from surface to a maximum value at an internal position and then decreases following an attenuation profile. The electron density buildup is uncompleted up to the maximum dose value. The electron density increases with deep, completing the electronic equilibrium. It occurs at 1.5 cm deep on the skin for

6 MV. The inclusion of a triangular filter may reduce the skin-deep distance in which electronic equilibrium is achievable. The lower dose at surface, less than the 100% that occurs at an internal point near surface, is due to the region of buildup [17].

In relation to the calibration process, the average absorbed dose in the TE skin for calibration with solid-water plates was 1.1 ± 0.1 Gy corresponding to 59 ± 8,5% of the prescribed dose; while, for the calibration with water phantom was 1.2 ± 0,1Gy corresponding to 68 ± 6,4%. The difference of the mean dose between the two calibration methods was 0.1 Gy representing 5.5% of the prescribed dose of 1.8 Gy. It may be because the difference in mass density of the water and the solid plates. This value is the minimum interval for sensitization of the EBT2 radiochromic film. Moreover, the uncertainty related to the experiment is greater than this value.

Analysis of the experimental uncertainties

Sources of uncertainties involved in the experiment were estimated as International Standards Organization (ISO). The uncertainties of the experimental measurements are difficult to be assessed because of the number of variables involved. The authors estimated a value for the combined experimental uncertainties of ±6% reliability factor K= 2 according to the value recommended by ICRU 24. This value was estimated after analyzing possible sources of uncertainties present in the experiment. This high estimated value is due to the large number of procedures and variables involved, which have not yet been subjected to any process of normalisation or standardization.

Conclusion

It is concluded that the two calibration methods with water phantom and solid water plates reproduces values with no significant statistical differences. Both are suitable for calibration procedures for Dosimetry based on radiochromic films. The mean doses found in the synthetic skin were 1.2 Gy who represented 64% of the prescribed dose.

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