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TECHNICAL PAPER

A simple and efficient method to measure beam attenuation through a radiotherapy treatment couch and immobilization devices

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Abstract
We propose a simple and efficient method to measure beam attenuation in one or two dimensions using an amorphous silicon electronic portal imaging device (a-Si EPID). The proposed method was validated against ionization chamber measurements. Beam attenuation through treatment couches (Varian Medical Systems) and immobilization devices (CIVCO Radiotherapy, USA) was examined. The dependency of beam attenuation on field size, photon energy, thickness of the couch, and the presence of a phantom were studied. Attenuation images were derived by computing the percentage difference between images obtained without and with a couch or immobilization devices determining the percentage of attenuation at the center and the mean attenuation. The beam attenuation measurements obtained with an a-Si EPID and an ionization chamber agreed to within ± 0.10 to 1.80%. No difference was noted between the center and mean of an attenuated image for a small field size of 5×5 cm^2, whereas a large field size of 15×15 cm^2 exhibited differences of up to 1.13%. For an 18 MV beam, the a-Si EPID required additional build-up material for accurate assessment of beam attenuation. The a-Si EPID could measure differences in beam attenuation through an image guided radiotherapy (IGRT) couch regardless of the variabilities in couch thickness. Interestingly, the addition of a phantom reduced the magnitude of attenuation by approximately 1.20% for a field size of 15×15 cm^2. A simple method is proposed that provides the user with beam attenuation data in either 2D or 1D within a few minutes.

Keywords Beam attenuation · EPID · Couch · Immobilization device

Introduction

In radiotherapy treatments, the use of immobilization devices allows reproducible setup of the patient throughout their treatment [1]. While these immobilization and support devices are essential for the spatial accuracy of the delivery, the devices themselves attenuate the incident beam, thereby affecting the dose received by the target. The impact of these support and immobilization structures has become a particular area of interest with the introduction of arc delivery techniques, because a significant portion of the target dose is delivered through the couch top and rails when these are

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present. Beam attenuation of up to 15% was reported for an Exact treatment couch (Varian) when the beam passes through a movable couch rail [2]. The overall beam attenuation magnitude through couches and immobilization devices varies depending on the structure of the couch and immobilization device used and is a function of the field size, beam energy, gantry angle, and the portion of the beam that passes through the device [3]. Studies show that a failure to account for beam attenuation through the treatment couch and immobilization devices can have a dosimetric impact. For example, Mihaylov et al. [4] reported an change in skin dose of 3800 to 2940 cGy for 6 MV for a volumetric modulated arc therapy (VMAT) plan with 6 and 18 MV photon energies, respectively. Similarly, Vanetti et al. [5] reported significant discrepancies as high as 2.50 Gy in the target volumes if calculations were performed without modeling the couch.

A recent review paper by the AAPM Task Group 176 emphasized that attenuation measurements are required to validate the treatment planning system (TPS) modelling couch and immobilization devices for use in independent monitor unit (MU) calculations and to verify the values supplied by the manufacturers for these devices. If the TPS is not able to model the attenuation caused by the couch and immobilization devices, the recommendation is to obtain attenuated data for the typical, as well as for the worst-case, clinical conditions for beam attenuation [3]. The conventional approach for measuring beam attenuation is to use an ionization chamber inserted into a phantom placed on the couch and then to compare relative readings with and without the couch in place [6]. Typically, an ionization chamber measures the beam attenuation in the center of the field only, whereas the couch and immobilization devices are non-homogenous structures. The ionization chamber also does not quantify the attenuation directly and only gives an estimate of the dose perturbation at the depth in the phantom [3]. The current practice of 1D measurement at the center of the field is insufficient to fully characterize the perturbation of the incident beam due to patient support devices, and therefore a 2D approach is recommended.

A variety of methods to measure the potentially more useful 2D beam attenuation have been proposed including radiographic film [7], 2D array of ion chambers (MatriXX) [8], and an electronic portal imaging device (EPID)-based CCD-camera that was clinically used as a dosimeter calibrated against 2D ionization chamber measurements [2]. With modern linear accelerators, the on board EPID is the most convenient method and provides 2D attenuated images.

In this work, we propose a simple and efficient method to measure beam attenuation using the current generation of clinically available amorphous silicon EPID detectors (a-Si EPIDs) without the need to convert the EPID response to a water-equivalent response. Unlike previous approaches, the proposed method allows the use of either 2D (the attenuated image) or 1D (the mean of the attenuated image instead of the center).

Method

Two S500 EPIDs mounted to a Varian 21iXs linear accelerator (linac) (Palo Alto, USA) were irradiated at a source-to-detector distance (SDD) of 150 cm. The linac produces photons of a nominal energy of 6 and 18 MV. Measurements were performed using two different couches: An Exact couch top and an image guided radiotherapy (IGRT) couch. An Exact couch consists of a couch top and two translatable sliding rails. Measurements were evaluated with the sliding rails moved away from the beam direction. This mimics the clinical case, where the rails are usually positioned outside the beam. An IGRT couch is not constant in the longitudinal direction, it has three different thicknesses of the couch top: thin (50 mm), thick (75 mm) and medium (62.5 mm). The immobilization devices examined were a Foamedic belly board made of 6–8 cm of foam (CIVCO Radiotherapy, USA), and a head and neck base board with Timo Med Tech Neck shape B (CIVCO Radiotherapy, USA). Measurements were acquired with a delivery of 100 MU utilizing a 6 MV photon beam and a dose rate of 600 MU/min, unless otherwise specified. Image Acquisition Software (IAS3, version 8.2.03) was used to acquire integrated EPID images.

Validation of the EPID measurements

The EPID-based beam attenuation measurements were validated by comparing them to measurements made with an ionization chamber (CC13, IBA) in combination with an electrometer. The ionization chamber was positioned on the central axis at a depth of 1.5 cm with a source-to-ionization-chamber distance of 150 cm for 6 MV. Beams at normal incidences were delivered using 100 MU and a field size of 5×5 cm^2 to minimize any scatter effects [2]. Measurements were carried out for the open beam, the beam through the Exact couch top, and the beam through homogeneous solid water slabs 2 cm, 4 cm, and 20 cm thick (RW3, PTW). These same measurements were then repeated using the EPID.

Beam attenuation measurement using EPID

First, a set of images was acquired for the open beam in the absence of the treatment couch; this set was designated $\left(Image_{Open}\right)$ The images were acquired with jaw defined square fields with sides of 5, 10, 15, and 20 cm to deliver 100 MU using 6 MV at gantry degree zero. A second set of images, $\left(Image_{Couch}\right)$, was acquired for the scenario where the beam passes through the couch and the immobilization device Measurements were conducted through the support

structures for similar fields at gantry angles of 0, 30, and 60°. No measurements were conducted in other gantry directions, since the assumption was that any angular dependence would be symmetric. Measurements were performed through the Exact couch, the IGRT couch, the combination of the Exact couch and the belly board, and the combination of the Exact couch and the head and neck base board (see the illustration in Fig. 1a). The couch was positioned at a source-to-surface distance (SSD) of 110 cm and the immobilization devices were positioned according to their normal clinical usage. Measurements were repeated twice and the means were calculated and recorded.

Beam attenuation dependency

$(Image_{Open})$ and $(Image_{Couch})$ sets were acquired with and without the couch top to deliver 100 MU for varying jaw-defined square fields with sides of 5, 10, 15, and 20 cm for a beam of 6 MV to examine the subsequent beam attenuation dependency. In some cases, the 20×20 cm^2 field size was not examined to avoid the presence of rails in the images.

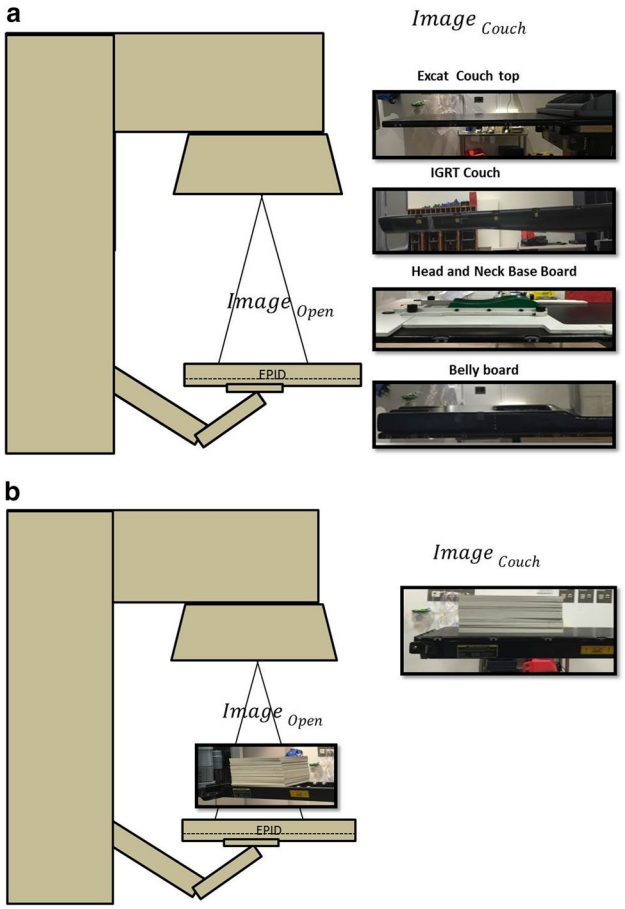

Fig. 1 **a** Illustration of experiment setup. EPID positioned at SDD 150 cm and couch positioned at 110 cm. Beam attenuation measurement conducted using Exact couch top without sliding rails, IGRT couch, Head and Neck Board and Bellyboard. **b** Measurement using phantom supported by sliding rail without couch grid to acquire $(Image_{Open})$, and phantom supported by couch top to acquire $(Image_{Couch})$

Field size dependency

Images were acquired using the Exact couch top for jaw defined square fields of sides: 5, 10, 15 cm at at gantry angles of 0 and 60°.

Photon energy dependency

Images were acquired using the Exact couch top for a photon energy of 6 and 18 MV. Measurements were taken at a gantry angle of 0°. The EPID for a beam of 18 MV requires external build-up material [9]; therefore, a 2.5 mm thick copper (Cu) sheet was added to the EPID panel. The thickness was determined according to the method of Sabet et al. [10].

Couch thickness dependency

Measurements were performed for the IGRT couch at different thicknesses: pelvis region (thick, 75 mm) and head region (thin, 50 mm).

Phantom dependency

In the clinical scenario, a patient would be present on the treatment couch; therefore, measurements were made with a phantom mimicking the patient. For the reference, images were taken with 20 cm of solid water resting on the extended couch rails without the couch present. The same measurements were then repeated with the couch in place (see Fig. 1b).

Data analysis

The acquired images were analyzed using MATLAB (VR2012b, MA). Attenuated images were derived by computing the percentage difference between measurements made without and with the presence of couch or immobilization devices, using the following equation:

$$2D\,Attenuatted\,image\,\% = \frac{Image_{Open} - Image_{Couch}}{Image_{Open}} \times 100 \quad (1)$$

For each 2D attenuated image, the percentage attenuation at the center, the mean, and the maximum were reported. The center of the attenuated image was assessed as the average of 11×11 pixels at the center of the field. The mean of the attenuated image was taken as the attenuation within

80% of the field, where the 80% region is defined as the area where the signal is over 80% of the maximum signal. The maximum of the attenuated image was reported as the highest value within the field.

Results

Validation of the EPID measurements

A comparison of beam attenuation through the couch top and solid water slabs, as measured using the ionization chamber and the EPID, is reported in Table 1. The magnitudes of beam attenuation measured using the EPID were similar to those obtained using the ionization chamber, falling within ± 0.10 to 1.80%.

Beam attenuation measurements using EPID

The magnitude of beam attenuation measured by the EPID through the Exact couch, IGRT couch, the combination of the Exact couch and belly board, and the combination of the Exact couch and the head and neck base board is shown in Fig. 2. Overall, at the normal incidence (gantry degree 0°), the highest beam attenuation was observed with the combination of the Exact couch and the head and neck base board, yielding a 9.60% reduction when using the mean of the image. The least attenuation was found for the IGRT couch, with a 2.50% reduction. As expected, the beam attenuation was increased by increasing the beam obliquity due to increases in the path length through the couch. The two greatest attenuation measurements were found for the combination of the Exact couch and belly board, at 11.20%, and the combination of the Exact couch and the head board, at 10.90% at 60° incidence. The Exact couch shows a more oblique dependency when compared to the IGRT couch. When the beam obliquity changed from 0 to 60°, the relative beam attenuation increased by 3.10% for the Exact couch and by 1.50% for the IGRT couch.

Table 1 Beam attenuation measurements using an ionization chamber and EPID, with 100 MU of 6 MV photons and a field size of 5×5 cm^2, EPID measurement values are derived from the centre of the attenuated image

Material	Ionization chamber (%)	EPID (%)
Couch top	3.0	3.2
Solid water of 2 cm	9.6	10.5
Solid water of 4 cm	18.3	20.0
Solid water of 20 cm	63.1	64.9

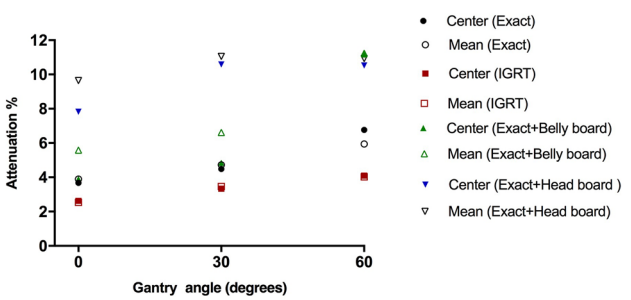

Fig. 2 Beam attenuation assessment using centre and mean value of attenuated images, centre is represented by a solid symbol and mean is an open symbol, each data point is the average of the four field size measurements of 5, 10, 15, 20 cm using 6 MV, and couches were positioned at 110 cm

When comparing the difference in beam attenuation values using the center and the mean of the field size, the results in Fig. 2 show that, for an attenuated beam with an IGRT couch, the difference between the center and the mean values was 0.10%. By contrast, for the Exact couch, the difference between the center and the mean values was 0.80% at an oblique beam incidence. The differences between the center and the mean of an attenuated image increased noticeably, to approximately 1.80%, when the immobilization device was involved. In most cases, the beam attenuation assessment by the mean of the attenuated image was higher than the beam assessment at the center. For example, at a normal incidence, the combination of the couch and head board attenuated the beam by up to 9.60% and 7.80%, using the mean and the center of the attenuated images, respectively.

The results of using the maximum percentage of the attenuated image (data not shown) demonstrated that the maximum value of up to 26.20% was attained for a combination of the Exact couch and head board at a gantry degree of 60°.

Beam attenuation dependency

Figure 3a shows the attenuation measurements as a function of field size through the Exact couch. A decrease in the beam attenuation was noted with an increase in field size and particularly with an oblique beam incidence. Attenuation was reduced within 1.00% and 2.10% for the center and mean of the attenuated images, respectively, when the side of the field increased from 5 to 15 cm. One outlier was observed when the attenuation was measured for a field side of 15 cm using the mean of an attenuated image for normal incidence. No difference was detected between the center and the mean of an attenuated image using a 5×5 cm^2 field size, whereas differences appeared with an increase in the field size of up to 1.13% for an oblique incidence.

Beam attenuation measurements as a function of photon energy are shown in Fig. 3b. The attenuation of 18 MV beams was lower when compared to 6 MV by 1.10% and

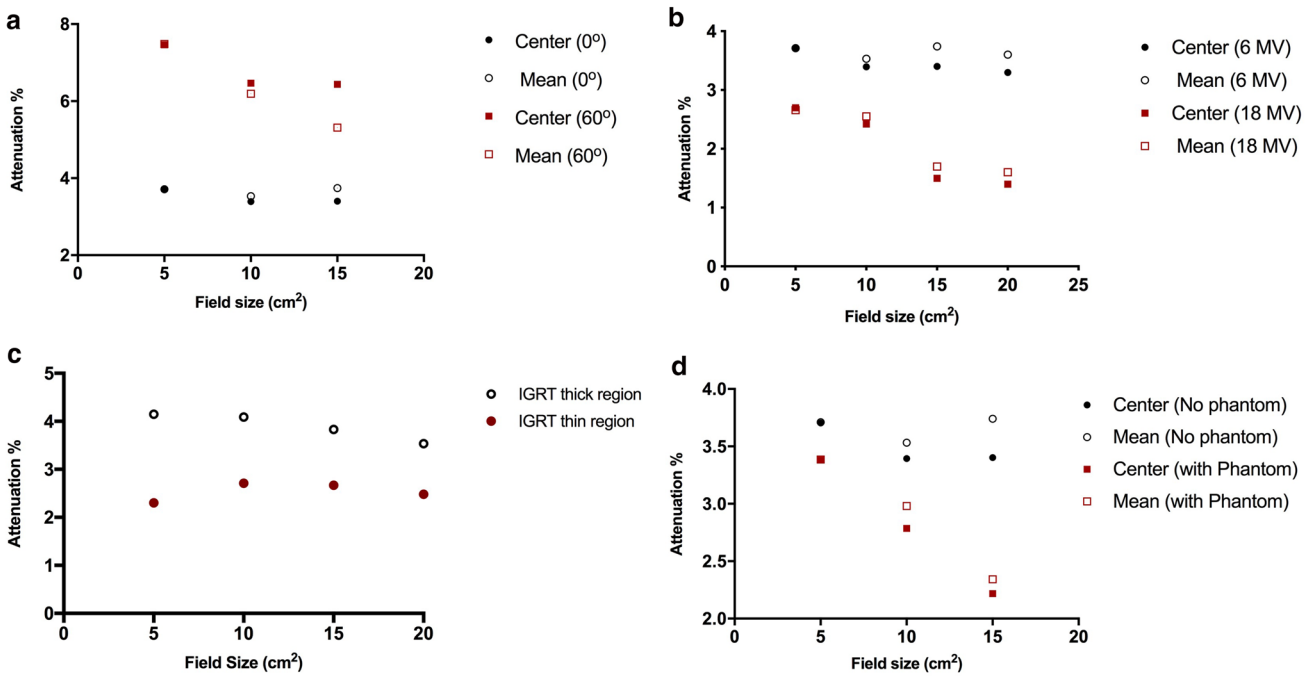

Fig. 3 **a** Beam attenuation through exact couch top as a function of field size for normal and obliquity of incidence. **b** Attenuation measurement as a function of photon energy using the centre and mean of attenuated image. **c** Attenuation measurement through IGRT couch as a function of region using mean of attenuated image. **d** Attenuation data with and without the exsitence of 20 cm solid water phantom

1.90% for field sizes of 5×5 cm^2 and 15×15 cm^2, respectively. Attenuation measurements through the different regions of the IGRT couch are shown in Fig. 3c. The varying thickness of the different regions caused a variation in the magnitude of the attenuation, depending on the region, and varied by up to 1.80%. For a thick (pelvis) region, the beam attenuation was between 3.83 and 4.14% for the range of field sizes tested. For a thin (head) region, the beam attenuation was within 2.30% and 2.71%.

The effect of including a phantom on beam attenuation is shown in Fig. 3d. Interestingly, the amount of attenuation decreases in the presence of the phantom, to between 3.40 and 2.20% for a large field size of 15×15 cm^2, and the reduction is field-size dependent.

Discussion

An EPID based measurement, such as the method outlined in this work, has the capability to provide 2D attenuation maps as well as 1D attenuation without any modification required to convert the EPID response to a water-equivalent response. The process presented in this work is fast to perform, taking only a few minutes to capture images and calculate the attenuation. The method could be applied to any EPID device from any vendor. The proposed method allows the user to use the 2D attenuated image to determine typical and worst-case attenuation conditions, representative clinical conditions, and to validate the predictions of the TPS. To enhance the comparison and calculation validity in independent MU calculations, instead of measuring the factor of attenuation at the center of the field and then applying this factor in an independent MU calculation, the mean of the 2D EPID attenuation map can be applied in the independent MU calculation. Finally, the method provides an easy way to compare measurements with manufacturer's data at the time of commissioning.

In the context of transit dosimetry, the use of EPID commercial dosimetry software to compare between the reconstructed dose by EPID and the dose from the TPS resulted in a difference in dose between the EPID system and the TPS as high as 15% in a heterogeneous region. This is because the EPID software does not account for the couch attenuation in the case of a transmission measurement [11]. Therefore, our study could be useful for quantifying attenuation factors for EPID images arising from the treatment couch and immobilization devices and using them to correct transit dosimetry calculations in 2D. Whereas, a 1D point dose measurement would only provide a rudimentary correction for that point on the projection, and, if applied incorrectly to the entire dose reconstruction, could over/underestimate the degree of attenuation.

The similarity between EPID images and ionization chamber attenuation measurements validates the suitability

of using an EPID to assess the beam attenuation due to couch and immobilization devices. The 2D beam attenuation was also examined in a variety of geometrical scenarios. The few studies conducted to date have only evaluated the impact of gantry angle and field size using 1D dosimetry in the center of the field [6, 12]. The results in Fig. 2 show how the beam attenuation increased with increasing obliquity of the beam. This finding agrees with the data from previous studies that measured beam attenuation using ionization chambers [6, 12]. The reason for the increased attenuation with an increase in obliquity of the beam is explained as an increased beam path length through the attenuator. In addition, the results in Fig. 2 demonstrate an angular dependence for the Exact couch compared to the IGRT couch. This indicates that the structure of the IGRT couch may be more homogenous than that of the Exact couch. The involvement of immobilization devices also increased the attenuation assessed by the mean of the image compared to attenuation assessd by the center. This is because the immobilization device is inhomogeneous, as shown in in Fig. 4.

The results presented in this work illustrate that the conventional approach of measuring attenuation in the center of the field may be insufficient. A 2D measurement in terms of providing additional information on the spatial variation of attenuation, a measuring attenuation using the mean could be important for inhomogeneous couch structures. For field size dependency, the results presented here show that attenuation decreased with an increase in field size. This was confirmed by a previous study, which reported a reduction of within 1 to 2% using an ionization chamber and explained this reduction as being due to the effect of scatter radiation [12]. The results in Fig. 3 demonstrate that, with oblique beam incidence, the center of an attenuated image was higher than the mean by 1.13%. This is because, in a smaller field size, the couch attenuates the entirety of the beam; therefore, the attenuation at the center and the mean of the field are similar. By contrast, with an increase in field size and beam obliquity, the beam passes partially through the couch and the attenuation will be dissimilar between the center and the mean, as shown in Fig. 5. The results highlight the importance of 2D mapping for the attenuation. Note that greater differences appear at the edge of the field in Fig. 5. This could be due to the effect of sagging of the EPID [13].

Our results in Fig. 3 demonstrated that build-up materials are necessary to measure beam attenuation at 18 MV and that the optimum build-up thickness is 2.5 mm of Cu. The attenuation by the couch was greater with lower energy photons, and our results confirm the findings by Njeh [12]. The impact on the delivered dose is more relevant at lower energy, as reported by Vanetti [5]. In addition, the results

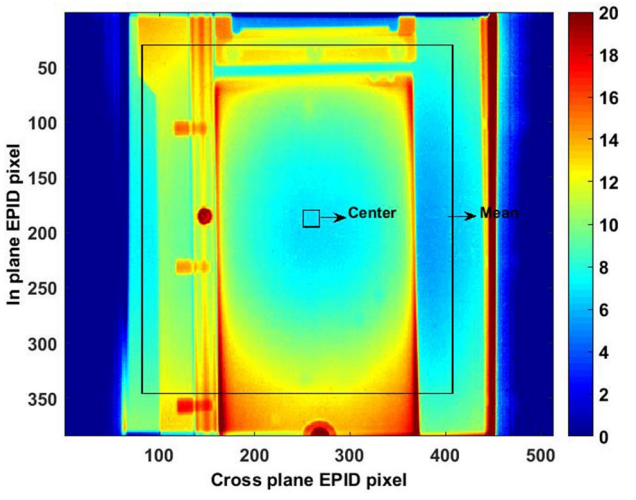

Fig. 4 Attenuated image through the combination of Exact couch and head and neck board at normal incidence using 6 MV and a field size of 20×20 cm^2

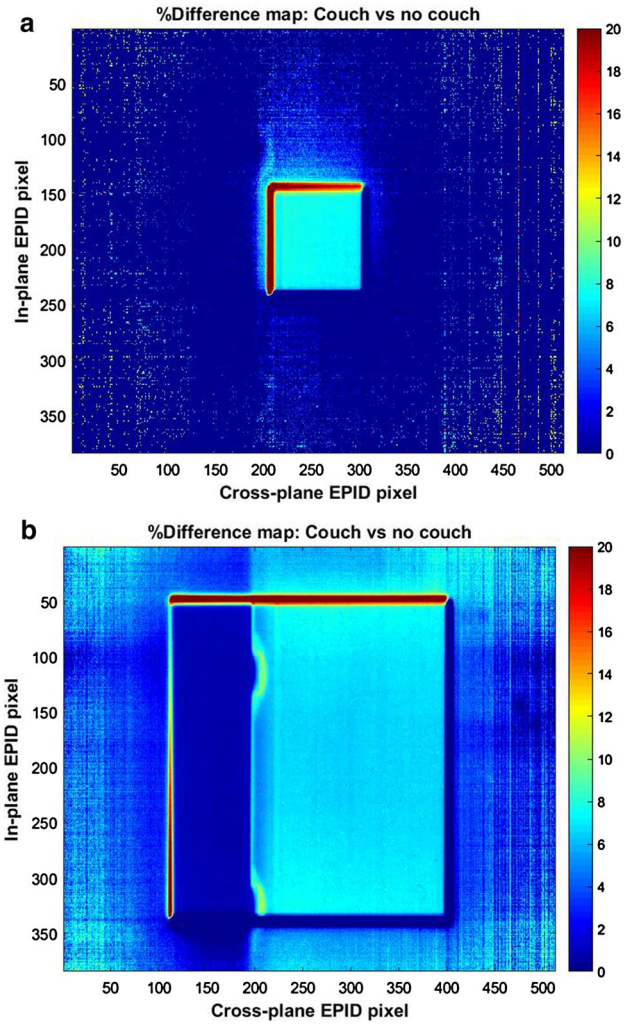

Fig. 5 Attenuated images with oblique beam (60°) using 6 MV and couch position at 110 cm as function in field sides, **a** 5 cm. **b** 15 cm

in Fig. 3 indicate that the magnitude of attenuation was reduced in the presence of a phantom. This could be due to increased scatter radiation, which consequently reduces the attenuation.

Conclusion

A simplified method of measuring beam attenuation through the treatment couch and immobilization devices using aS500 EPID is presented and validated against ionization chamber measurements. This approach is efficient and can provide attenuation data in 2D or 1D in a few minutes. The application of the mean of the field provides a more accurate estimation of the beam attenuation than does application of the center of the field. We have quantified beam attenuation through couches and immobilization devices as function of field size, photon energy, thickness of the couch, and the presence of a phantom. These attenuation measurements might be useful for quantifying the effect of attenuation arising from treatment couches and immobilization devices on EPID images when an EPID is used for transit dosimetry.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants performed by any of the authors.

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