Observation study of electronic portal images for off-line verification

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Abstract

Purpose: The goals of this study were to evaluate the use of electronic portal imaging device (EPID) paper images as off-line verification tools and to assess the feasibility of replacing portal films by EPID printed images.

Materials and methods: Electronic portal images were acquired using a video-based imaging system. After contrast enhancement, these images were printed and compared to portal films when prescribed, and judged about their usefulness for off-line verification. A total of 2025 images were acquired from 322 fields on 137 patients. The images were shown to eight radiation oncologists and two senior residents in radiation oncology, each one of them judging fields relevant to his (her) daily practice. The questions asked were related to the choice of important anatomical structures and the visibility of such structures, the usefulness of the printed images, the comparison with portal films and the possible replacement of such films by paper images.

Results: Answers to the different questions were treated as quantitative scores. For the visibility question, means and standard deviations were calculated for each individual structure, then a global score was obtained for a given treatment site. Means and standard deviations were also computed for the comparison question. Proportions and confidence intervals were used for the other questions. The results show that EPID paper images are useful for some treatment sites such as breast, thorax, prostate, abdomen, pelvis (other than rectum) and axilla. The image quality remains insufficient for some other sites such as head and neck and spine.

Conclusion: Although global anatomical landmarks scores are good, the usefulness score is not always as high because some essential anatomical structures scores must be taken into account. There is also a strong habit factor related to acceptance of EPID printed images as verification tools. As long as they see more and more images, radiation oncologists can more easily visualize anatomical structures and are less stringent when evaluating the efficiency of EPID paper images as off-line verification tools. © 2000 Elsevier Science Ireland Ltd. All rights reserved.

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1. Introduction

The aim of radiation therapy treatments is to deliver an adequate dose to the tumor while sparing normal tissues as much as possible. Some studies have shown that adequacy in patient positioning resulted in a better outcome, both theoretically and in an objective way [10,15,19,27,38] and many reports on field placement errors detected by verification films have been published [4,14,20,21,31]. During the 90’s, many improvements on the different technologies used for electronic portal imaging (EPID) [3,25,34] have led to the increase of its use for verification purposes, off-line and on-line [2,5,7,8,11,13,18,22,23,30,32,35]. Some authors have also looked at the frequency of corrections on the field placement that would be appropriate, using algorithms [1,2,23,30].

The on-line verification of the treatment field, with the possibility to rapidly catch a field positioning error and to make the necessary adjustment immediately, is certainly the most striking advantage of electronic portal imaging devices. Its availability increases the confidence level that an adequate treatment is delivered.

There are many circumstances where off-line verification based on the acquired image would be useful. This could happen, for instance, when a technologist needs to consult the radiation oncologist about a precise problem in the positioning of a particular patient. It could also be very convenient to use EPID for the regular verification of treatment fields by the radiation oncologist. Obviously, electronic portal images are best represented on a computer screen. There is inevitably a degradation of the image quality on the hard copy. However, at our institution, before each radiation oncologist becomes adequately equipped and trained to efficiently use a computer for that purpose, the usefulness of such an expense must be established. For the
time being, there are many advantages to get a printed paper image. This image can easily be inserted into the patient chart as a legal print-out and is handily available. This procedure would also fit in a setting of resource limitations and busy radiation treatment schedules. EPID paper images actually cost less, are easier to store and require less time and handling for acquisition than portal films.

EPID is already extensively used in our department, offline, for routine verification of tangential breast irradiation [18] and often for whole-brain irradiation, and on-line by the technologists to confirm set-up accuracy for many patients, modifying the set-up when necessary. It has also been employed in a research setting [36], in a perspective of 3D conformal therapy.

The purpose of the present study was to compare the use of EPID to the use of portal films as a regular verification tool for an extensive variety of treatment sites, keeping in mind the practical issues already mentioned. This would be of great help in our department, where about 225 patients are treated every day. The goal was also to test the usefulness of EPID images for verification of fields for which portal films are not routinely used because of insufficient film quality. This could lead to improved treatments in terms of set-up accuracy. Because the convenience of EPID images is greater than that of portal films, we could eventually verify treatment portals more frequently. This could also improve treatment quality. A number of centers are considering the issue of using EPID for off-line verification or are indeed doing it [6,12,39]; and the trend is towards emphasizing the use of EPID in a clinical setting [26]. Yin et al. have concluded that verification of treatment ports based on EPID images was generally achievable and that the visibility of anatomical landmarks was comparable to that of portal films with the exception of lateral pelvic fields [39].

An important difference between this study [39] and the present work is the exclusive use of 6-MV photons treated fields in theirs and the use of both 6- and 23-MV photons treated fields in ours. Another difference from the three other reports [6,12,39] is the imaging system technology used, the other centers having a liquid ion-chamber device (Varian Portal Vision), while in the present study, a network of video-camera based EPID systems (BeamviewPLUS from Siemens Medical Systems) was used.

For this study, the images were processed using a set of eight CLAHE (contrast limited adaptive histogram equalization) [16,17,24,28,33] degrees. This tool was implemented in our department by the second author to refine image quality. This study includes the choice of the best level of CLAHE for each treatment field observed.

2. Materials and methods

2.1. Images

Prior to the start of image acquisition, a survey was conducted with the radiation oncologists to define a set of anatomical structures needed to be seen on the images for the majority of treatment sites. This survey was also meant to choose fields for which it would be interesting to have verification material that we do not already have because of poor film quality.

The imaging system used consists of a copper metallic plate with a gadolinium oxysulfide (Gd₂O₂S) screen viewed through a 45° mirror by a Newvicon video camera (BeamviewPLUS from Siemens Medical Systems) [34]. This camera is connected to a frame grabber controlled by a workstation (Sun, Unix). Five accelerators are equipped with this EPID system in our center, three with 6- and 23-MV energies, one with only 6-MV energy and one with 4- and 6-MV energies, although no image was acquired using 4-MV photons in this study. The system is attached to the linear accelerator and retractable and the focus-detector distance is 139 cm. This system covers a 31 × 25 cm² area with 512 × 480 pixels on digital images. All EPID systems are part of a network and images can be viewed and processed from a central database.

A comparison of 2025 images about 322 fields on 137 patients (145 sets of images: eight patients having initial fields and reduced fields) was performed. Patients were often treated with several treatment fields and for each field, several images with different contrast enhancement values were presented to the observers. All 322 original field images were acquired and recorded by the main author, from 127 patients, from July 8th 1996 until November 21st 1996, except for the 40 original prostate images (ten patients) which were taken from an earlier study that took place in 1994 [37]. The images used were verification images acquired throughout the complete duration of the patient treatment, at a rate of 30 images per second, averaged over eight images. These images were processed using a CLAHE (contrast limited adaptive histogram equalization) tool [16,17,24,33] with eight clipping levels, (0.4, 0.8, 1.0, 1.2, 1.4, 1.6, 2.0, 3.0), a higher level meaning a more contrasted image. For details about CLAHE, the reader is referred to explanations available in the literature [16,17,24,28,33].

This CLAHE tool is part of an application program called ‘Portal’ [29] developed at our institution. All the processing was done on a remote workstation (Sun, Unix) in the physics research laboratory. Some CLAHE levels were excluded for many of the 322 fields when two images looked too much alike or when the quality was appropriate without the need of further contrast.

The 2025 images were printed employing a 600-dpi laser printer (Laser Writer Select, Macintosh, Apple) identical to the one available for printing from the accelerators workstations (Sun, Unix). In our department, two laser printers are connected to the accelerators workstations and other remote workstations located in the physics research laboratory.
2.2. Films

The portal films used were XV2 films (Kodak X-Omat V, Eastman Kodak Company) – no film cassette, and double exposure films (Chronex, Dupont) – using a film cassette (Kodak, Eastman Kodak Company). These double exposure films are the same as those used for simulation, but the quality is obviously poorer under treatment conditions, because of the radiation energy used [34]. The portal films were not necessarily acquired in the same treatment session as the EPID images, which was different from the study by Yin et al. [39].

2.3. Observation

An observation review of the images was organized, including simulation films to watch the prescribed portals, verification films when prescribed, the original raw EPID images and contrasted images. There were 78 head and neck fields (15 larynx, 63 others), 65 thoracic fields, eight axillary fields, 42 tangential breast fields, 16 abdominal fields, 92 pelvic fields (33 rectums, 40 prostates, 19 others), six spinal fields, nine bone fields (other than spinal) and six CNS fields (portals slightly different from whole-brain irradiation). The reason for obtaining breast fields, although routine breast off-line verification is already done in our center, was to try to improve heart and lung contrasts, as suggested by a radiation oncologist. These images were shown to eight radiation oncologists and two senior residents in radiation oncology, each one of them evaluating ports consistent with his (her) routine practice. They had to answer to a series of questions about each field.

Question 1 was about the choice of the best CLAHE index. Question 2 asked to indicate the necessary anatomical landmarks to be seen. A list was provided for every fields grouping named earlier. Other structures could be added to the list if needed. Then the observers were asked about the adequacy of visualization of these structures, on the EPID image with the CLAHE index chosen as the best and on the film when a film had been prescribed, which had occured in 44% of the fields observed. Question 3 asked to compare the best contrasted EPID image to the verification film when such a verification film existed. Question 4 asked if the best contrasted EPID image was useful or not. A useful image means that the features wanted by the radiation oncologist are of sufficient quality on the image such that it can play a role in the off-line verification process of a radiation treatment. Question 5 asked if the best contrasted EPID image could replace the verification film when such a film existed. Question 6 asked if there was a problem preventing the use of the EPID image as a verification tool and to specify this problem. The observers could also make general comments about the images.

No time limit was imposed for the observation of one field, each situation being different and requiring a different duration.

To present the results, the mode and the mean were used for question 1. Answers to question 2 were treated as quantitative ratings; means and standard deviations were computed for each anatomical structure, then a global score was obtained for each fields grouping. Answers to question 3 were also treated as quantitative data, and means and standard deviations were calculated. For questions 4 and 5, confidence intervals for proportions were extracted from tables available [9]. Finally, results of question 6 were commented in the discussion.

Although images were not seen by all radiation oncologists, it was possible to extract a subset of portal images from similar fields from different patients showing similar structures that were evaluated by several observers. It was therefore possible to assess the inter observer variability by sorting the data by radiation oncologist. For the same structure visibility and for image usefulness, the inter observer standard deviations were computed and compared to the standard deviations computed for each observer individually. A few examples will be presented in the results section.

3. Results

3.1. CLAHE

Modes and means for the CLAHE index chosen were calculated. For breast images, 0 was the most frequent CLAHE index chosen, so there is no real need for contrast improvement for breast tangential fields. For spine and larynx images, the result most often obtained was that no CLAHE index could be chosen because of insufficient quality. For those sites, the mean was calculated from the results obtained when a CLAHE index could be chosen. Generally, it can be shown that low CLAHE index are preferred. Clipping levels most often chosen were 0.8 for abdomen, axilla, bone (other than spine) and head and neck (other than larynx), 0.4 for rectum, thorax and pelvis (other than rectum and prostate) and finally 1.0 for prostate.

3.2. Structures (individual)

Mean scores and standard deviations for each structure indicated in the observation of every treatment site were obtained. A graph was computed for each treatment site, one for images and one for films when films were prescribed. Some of these graphs are presented on Figs. 1–6.

Structures are generally well observed on breast images. On thoracic images (see Fig. 1), soft tissues are well visualized and bony structures are partially visualized. In general, observation of landmarks is slightly better on thoracic films, with the same tendency mentioned earlier concerning bone versus soft tissues.

Visualization of structures is better than partial on prostatic AP-PA images (see Fig. 2), and is partial on lateral prostatic images. No verification film was prescribed for
prostate fields. Visualization of anatomical structures is
good on abdominal images (see Fig. 3) and films, and is
even better on images for some structures. On pelvic
(other than prostatic and rectal) images, it is difficult to
see vertebrae. Many bony landmarks are easily visualized,
although certain femoral structures are not well visualized.
The visualization of structures is good on the one pelvic
(other than prostate and rectum) film that was prescribed.

Visualization is difficult on spinal images. Vertebrae are
easily seen on spinal films, with the exception of transverse
processes. Again, only one verification film was prescribed
for that type of fields, mainly used for palliation. On axillary
images, visualization of landmarks is good (see Fig. 4) and
comparable to that on films. On bone (other than spine)
images, structures are easily observed. On CNS images,
landmarks are well visualized except for vertebrae. No
verification film was prescribed for bone (other than
spine) and CNS fields.

Soft tissue structures are generally well visualized on
both head and neck (other than small glottic) images (see
Fig. 5) and films. Blocks can easily be verified on both
modalities, except for medullary blocks on images. It is
easier to observe bony structures on the head and neck
films than on images. Bony thoracic landmarks on inferior
cervical AP projections as well as vertebrae are also more
easily visualized on films than on images.

On rectal (AP-PA) images, visualization of landmarks is
generally partial (see Fig. 6). No verification film was
prescribed for that type of fields. Visualization of structures
is not good on lateral rectal images, and is better on the two
lateral rectal films that were prescribed for these fields.

Many structures are hardly visible on laryngeal (glottic)
images, and this applies to bony as well as soft tissue land-
marks. The anterior limit of the fields (skin) is well visu-
alized. It is much easier to recognize anatomical landmarks
on laryngeal films.

Fig. 1. Visualization of thorax structures on images. Visualization on x-axis: (point) mean and (horizontal line) standard deviation, (0) good, (1) partial, (2) none, (*) undetermined standard deviation. Structures on y-axis, (*) being able to count vertebrae.

Fig. 2. Visualization of prostate AP-PA structures on images. Visualization on x-axis: (point) mean and (horizontal line) standard deviation, (0) good, (1) partial, (2) none. Structures on y-axis.

Fig. 3. Visualization of abdomen structures on images. Visualization on x-axis: (point) mean and (horizontal line) standard deviation, (0) good, (1) partial, (2) none. Structures on y-axis, (*) being able to count vertebrae.
3.3. Structures (global)

Fig. 7 presents the global results for each site. Global scores show that structures are well visualized on breast images, thoracic films, pelvis (other than prostate and rectum) images and films, axilla images and films, bone (other than spine) images, head and neck (not larynx) films, lateral rectal films and laryngeal films.

Visualization of structures is good on thoracic images, prostate AP-PA images, abdominal images and films, spinal films, CNS images, head and neck (not larynx) images and rectal (AP)-PA images.

Landmarks are partially visualized on lateral prostatic and lateral rectal images. Finally, structures are almost not visible on spinal and laryngeal images.

These global scores do not always reflect the results of the usefulness of EPID images as verification tools. The individual structures scores must be taken into account, since the visualization of some structures seems more important than that of others in making a clinical decision. This will be illustrated by the next results.

3.4. Comparison, usefulness and replacement

Graphs of the results of the first two questions are presented on Figs. 8 and 9.

3.4.1. Comparison

Only abdominal images are considered being of better quality than films. Thoracic and axillary images are considered somewhat worse than films. Pelvic (other than prostate and rectum), spinal, large head and neck, lateral rectal and laryngeal images are considered worse than films (see Fig. 8). Pelvic (other than prostate and rectum), spinal and lateral rectal images did not prove to be of better quality than films on the rare occasions a comparison was made for these

Fig. 4. Visualization of axilla structures on images. Visualization on x-axis: (point) mean and (horizontal line) standard deviation, (0) good, (1) partial, (2) none. Structures on y-axis.

Fig. 5. Visualization of head and neck (not larynx) structures on images. Visualization on x-axis: (point) mean and (horizontal line) standard deviation, (0) good, (1) partial, (2) none, (*) undetermined standard deviation. Structures on y-axis, (*) being able to count vertebrae.
fields. These are sites for which verification films are seldom prescribed because of defective quality.

3.4.2. Usefulness

Breast images are undoubtedly useful. Thoracic, prostatic, abdominal, axillary, pelvic (other than prostatic and rectal), bony (other than spinal), CNS and rectal (AP)PA images are judged as useful most of the time. Lateral rectal images are useful half of the time. So prostate, pelvis (other than prostate and rectum), bones (other than spine) and rectum are sites for which images are generally considered useful although these represent sites for which verification material was not routinely used because of poor film quality. Head and neck (other than larynx) images are not often useful and finally, spinal and laryngeal images are never useful (see Fig. 9), meaning that for those fields, EPID images are not of sufficient quality to be used as verification tools.

3.4.3. Replacement

Abdominal films can often be replaced by images (in a proportion of 70%). Thoracic and axillary films can be replaced thirty to 40% of the time. Head and neck (other than laryngeal) films could be substituted by images about 15% of the time. Spinal, lateral rectal and laryngeal images cannot take the place of verification films.

3.5. Inter observer variability

This question was addressed by comparing the results of similar treatment fields on different patients. For inter observer variabilities, images of different patients from similar treatment fields judged by different radiation oncologists were used. For intra observer variabilities, images of different patients from similar treatment fields judged by the same radiation oncologist were used.

The inter observer variability values are smaller than the intra observer variability. For instance, for the ability to count vertebrae on large lateral head and neck fields (not glottic), the inter variability is 0.08 while the intra variabilities for three radiation oncologists are 0.40, 0.50 and 0.52. Similarly, on mediastinal fields, the inter variability for the same landmarks is 0.25 while individual variabilities are no variability, 0.50 and 0.58. On the same fields (mediastinal), bifurcation (carina) visibility inter variability (0.14) is small while intra values range from no variability to 0.50.
Similar results are found for the question investigating the usefulness aspect of the images. In particular, inter variability for mediastinal fields is 0.24 with intra observer values of no variability, 0.50, 0.58 and 0.58. For large head and neck fields, values of 0.33 and 0.31, 0.31, 0.52 were obtained for inter and intra variabilities, respectively.

3.6. Correlations

Graphs of correlations between the different questions were computed. Although some trends could be noticed, no strong correlation could be underlined. This shows that the observers made an effort to answer each question independently. For instance, in spite of a quite high global score for head and neck fields structures, images were considered rather not useful for this type of field because some important structures such as vertebrae were not visible (see Fig. 10).

4. Discussion

The most common and important problems related to the use of EPID paper images and the most frequent comments made by the observers will be stated in this section. An exhaustive listing of the problems and comments reported would be beyond the scope of this article.

The general comment was made that printed images would be more useful with a small improvement of image quality. For instance, although precautions are taken with CLAHE to get optimal field borders, observers had still some trouble identifying field edges in more than ten percent of the fields observed. Another problem involving borders is that for large fields (mantle fields for instance), there is sometimes a field border missing because the EPID detector is not large enough. This should be noted when the EPID image is submitted to the radiation oncologist for verification. The EPID image could still be useful for verifying the other limits and the general treatment setting.

On many occasions, the EPID image was considered adequate to verify the global positioning of the patient while it was still difficult to identify specific structures. On the other hand, poor visualization of vertebrae was addressed as a specific problem preventing the use of EPID images for verification in more than half of the head and neck (other than glottic) fields, in more than a third of the thoracic fields, in one fifth of the paraortic fields and in one third of the CNS fields.

An improvement made from the outcome of the present study was to include in the ‘Portal’ program the CLAHE index mode for each treatment site. This way, the adequate CLAHE index related to the involved anatomical site is automatically obtained.

The important anatomical structures to be visualized were chosen by the radiation oncologists. The approach was different in the study by Yin et al. [39]. Also, in the present study, time was taken to obtain optimal processing of the images, and the best images selected by the radiation oncologists submitted to the observation study. This was also different in the previous study [39].

In this study, an advantage inherent to the image technology employed (BeamviewPLUS from Siemens Medical Systems) is the allowance of making measurements. For instance, the Central Lung Distance is routinely verified for tangential breast irradiation [18]. It is more difficult with the technology used in the other studies [6,12,39] due to deformation of the image (Varian Portal Vision).

As in our study, results of Yin et al. [39] show that vertebrae are not easily seen on head and neck and thoracic fields. However, our results demonstrate that this fact greatly impede the usefulness of EPID images, at least for head and neck fields. Visualization of the vertebrae helps evaluating the length of a treatment port and the position of a treatment field related to specific vertebrae. Also, the spinal cord is a critical structure in radiation oncology, and since it is not visible directly, we must rely upon the vertebrae to get information about it.

Conclusions of the study by Yin et al. [39] were essentially made on landmarks scores. In this study, we emphasized the fact that some anatomical structures are more important than others when evaluating the usefulness of EPID as a verification tool.

People take time getting used to a new technology, and reluctance to change is even greater when another instru-
ment has been used for years for the same purpose. In this study, two observers were senior residents who had already used EPID extensively for research. These observers judged the images as useful more frequently than the other observers. We could also notice, as long as the observation study was moving forward, that radiation oncologists were getting used to EPID images, and were not choosing the same anatomical landmarks anymore, as though they were adjusting to the images.

5. Conclusion

EPID printed paper images are useful for off-line verification of radiation oncology treatment fields for different anatomical sites such as breast, thorax, prostate, abdomen, pelvis (other than prostate or rectum), axilla, bone (other than spine), CNS and (AP)-PA rectal fields. They could also be useful for lateral rectal fields. However, they are not useful for spinal, large head and neck and small laryngeal fields. There is still room for improvement of image quality.

It is important to notice that although some global anatomical landmarks scores are high for given treatment sites, some essential anatomical structures scores weigh more in the balance than other structures scores when judging the usefulness of EPID images. These specific scores are also important when evaluating the possible replacement of traditional verification films by EPID images, and were stated as problems hindering the optimal use of EPID as a verification tool.

Finally, there is a strong habit factor linked to acceptance of EPID as a verification instrument. As long as they observe more and more images, radiation oncologists get used to this type of images and become less stringent when making a judgment about the efficiency of EPID images as off-line verification tools.

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