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Developing a PC-based portal image contrast enhancement program

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Background: Delivering the radiation dose to the target volume and minimizing the dose to normal tissues are the main objectives in radiotherapy. The aim of our study is to enhance the contrast of the portal image to increase the accuracy of delineation of the organs in the irradiation field. **Materials and Methods:** The software was written based on local enhancement of the pixel values in image matrix. The portal images were digitized by charged coupled device (CCD) in compatible format to be read with this program. This program was applied as an m-file in MATLAB imaging tool box to the matrices of the portal images. The imaging parameters before and after application of the program were compared. **Results:** The quantitative information of images was obtained. Analysis of the mean and standard deviations of the results has shown that the difference of the criteria between two groups of the images is significant ($p < 0.01$). In qualitative analysis, final images scores were based on "special weight ". The result of this test confirms the superior quality of the post-processed images from the professional view point. **Conclusion:** Superiority of final images within the three studied parameters by the experts (superiority of lung image, superiority of thorax and its soft tissue images) can be used to increase the accuracy of the treatment set up and decrease the probability of normal tissue complications. **Iran. J. Radiat. Res., 2005; 3 (1): 37-42**

Keywords: *Contrast enhancement, radiotherapy, portal imaging, MATLAB, imaging tool box.*

INTRODUCTION

Radiotherapy is mandatory for irradiation of the chest wall in total mastectomy patients. It has also been emerged to be the alternative to total mastectomy after conservative surgery for patients with early breast cancer. The standard treatment uses tangential, parallel opposed fields to obtain a homogeneous dose to the entire breast and to spare the normal surrounding tissues, particularly the lung and heart[1, 2].

Verification of the treatment field and quality control are the essential steps of the treatment procedure to decrease the overall uncertainty to reach to an acceptable level of standards with the available equipments. Many sources of errors exist, among which positioning or the accuracy in directing the beam to ensure the precise coverage of the target volume may be the weakest link in the chain, especially in non-equipped tele-radiotherapy machines. Positioning errors result both in underdosage of the target volume and unnecessary irradiation of normal tissue leading to a decrease in the probability of local tumor control and an increase of normal tissue complications. Thus, the verification of the field alignment with portal films can increase the accuracy by identifying localization errors[3]. It has been reported that important reduction in localization errors can be achieved with an increasing frequency of portal films[4-6]. As conventional portal films remain the only routinely available technique in most centers, its disadvantages such as poor image contrast, time-consuming process and high cost of advanced facilities, make its frequent use very reluctant. The most advanced radiotherapy machines are equipped to the real-time electronic portal imaging device (EPID) to verify whether the irradiated volume is confined to the target volume or not[7-9]. Another use of the portal imaging system is for on line dosimetry verification[10]. However, still the high cost of such equipment causes a very few centers to be able to use from this high technique facilities.

In this paper, we introduce a PC based software method of contrast enhancement to improve the quality of the chest wall portal images of the patients undergoing routine breast radiation treatment.

MATERIALS AND METHODS

Twenty two partial or total mastectomized

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patients undergoing tangential irradiation were entered in this prospective study. Among them 13 patients had conservative surgery (intact breast) and 9 were totally mastectomized.

The irradiation approach in our department for chest wall treatment consists of a fixed source to skin distance technique with the patient in semi-supine position on a breast wedge-shaped support and with arm abducted, so that the dorsal beam edge to be parallel to the sternum. To reduce the amount of lung and/or anterior wall of the heart included in the treatment volume, medial and lateral tangential ports were used routinely. Sagittal and longitudinal lasers were also used for positioning set-up. All patients were treated with a Cobalt-60 (Theratron 780) teletherapy machine with 1.25 MeV average photon beam energy.

To obtain portal images a dedicated cassette holder was tailored (figure 1) in addition to the modification of a 24 × 30 radiography cassette. The intensifying screens were removed, and were replaced by a 1 mm thick lead sheet on cassette front. Films were processed by conventional automatic processor. The cassette holder was positioned so that the image receiver face was perpendicular to the central ray axis and the cassette could cover all the irradiated field area.

A PC based charge-coupled device (CCD model: RAD system) with 8 bits per pixel and with pixel resolution of 640 × 480 was used to digitize the portal images. All the images had the same "TIFF" format compatible to the image processing tool box of the MATLAB

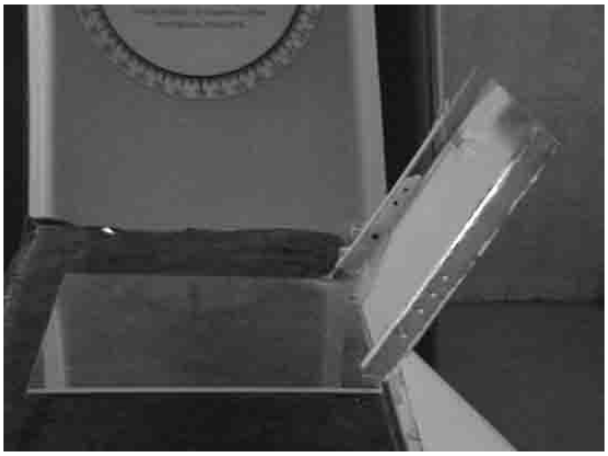

Figure 1. The dedicated cassette holder made from perspex is shown on the treatment couch.

version 6.0. Digital images were obtained for medial tangent portal films for all 22 patients, so that, at the end there were 22 non-digital and 22 digitized images to be compared.

The kernel, T, which was dedicated for the portal film contrast enhancement is based on the local enhancement of neighborhood pixel method. "T" is the transformation function which operates on the original image function, f, to induce the final image function of g. The transfer function operates on spatial domain, (x,y), on original image function. Therefore, the overall enhancement procedure is:

$$f(x,y) * T = g(x,y)$$

The kernel, T, is a 3 × 3 matrix which is convoluted over the original image matrix. As the "T" moves over the original image, it calculates the neighborhood pixels mean and standard deviation of the image matrix. The algorithm of the program is shown in equation 1.

$$g(x,y) = A(x,y)*[f(x,y)-m(x,y)]+m(x,y) \quad \text{(Eq. 1)}$$

Where the A(x,y) and m(x,y) are the modified value of the mean and the standard deviation of the image matrix, respectively. The value of A(x,y) is obtained from:

$$A(x,y) = k\, M/\sigma(x,y) \qquad 0 < k < 1$$

The coefficient k is a dimensionless number which can be varied according to the type of the image or the desired information. Its value is equal to 0.75 in this project. The M and $\sigma(x,y)$ are the neighborhood pixels mean and variances of the image matrix values, respectively.

After obtaining the original and final images, they were analyzed both quantitatively (numerical) and qualitatively (interpretational). Quantitative analysis was done on the statistical parameters consisted of the means and the standard deviations of both before and after processing images. The difference of the statistical parameters was tested by student's *t-test* and it was significant if the p-value was less than 0.05.

Qualitative analysis was obtained by means of the questionnaire handed to the three radiation oncologists. The images after processing were scored (0-3) in compare to the original images for the visibility of substructures in each image. Finally, the significant level of the difference between the scores and the original value (0) was tested by “expert opinion” test.

RESULTS

We designed and tailored the cassette holder to obtain the portal film of the patient during radiotherapy of the tangential field of the chest wall. This adjustable holder can tolerate the weight of a 24 × 30 radiography cassette.

The image processing program is written in MATLAB “m.file” (table 1). The program is user friendly and it starts with inputting the original image with command of “imread” in the MATLAB environment. The program has three main sections; 1) the input, image matrix format correcting and introducing prompt, 2) the core of the program consisted of kernel, calculation of mean and standard deviation, convolution function and operating the transfer function on the original image to produce the matrix of final image and 3) output section; consisted of the images before an after processing and their related histograms. An image histogram is a chart that shows the distribution of intensities in an indexed or intensity image. In this plot by making “n” equally spaced bins, each representing a range of data values, the number of pixels within each range is calculated (figure 2).

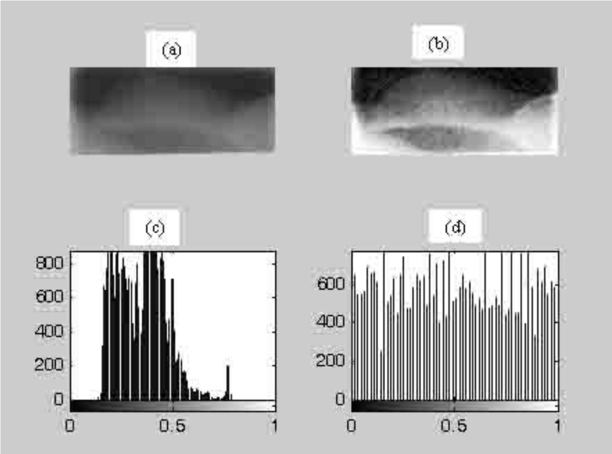

Figure 2. The input and out put of the program is shown. a) original portal image, b) post-processed image, c) the histogram before processing and d) histogram after processing.

Text images were defined as matrix deviation standard (Std) and average (Mean) and can be sourced from the MATLAB‘s instructions. Analyses of the mean and standard deviations of the results have shown that the difference of the criteria between two groups of the images is significant (p< 0.01).

Table 1. A part of second section of the program which shows calculation of standard deviation and main operation.

```
tavg=[f(i,j)+f(i-1,j-1)+f(i,j-1)+f(i-1,j)+f(i+1,j+1)+f(i+1,j)+f(i,j+1
)+f(i-1,j+1)+f(i+1,j-1)]/8;
avg1=(m(i,j)-f(i,j)^2;
avg2=avg1+(tavg-f(i-1,j-1))^2;
avg3=avg2+(tavg-f(i,j-1))^2;
avg4=avg3+(tavg-f(i-1,j))^2;
avg5=avg4+(tavg-f(i+1,j+1))^2;
avg6=avg5+(tavg-f(i+1,j))^2;
avg7=avg6+(tavg-f(i,j+1)^2;
avg8=avg7+(tavg-f(i+1,j-1))^2;
avg9=avg8+(tavg-f(i-1,j+1))^2;
s(i,j)=sqrt(avg8/9);
      %(i,j)=sqrt[(sum((m(i,j)-f(i,j))^2))8/];
      if s(i,j)=0;
         a(i,j)=1;
        else
                        %a(i,j)=[M/(s(i,j))]*.75;
      a(i,j)=(s(i,j))*0/75;
            %g(i,j)=a(i,j).*[f(i,j)-tavg]+tavg;
      g(i,j)=a(i,j).*[f(i,j)-m(i,j)]+m(i,j);
        end
     end
  end
```

Qualitative analysis was done in order to propose if the numerical assessment can be reliable for deciding the superiority of the post-processed images to the pre-processed ones. Since pre-processed images score were "0", final images scores were based on "special weight". The result of this test confirms the superior quality of the post-processed images from the professional eyes view.

DISCUSSION

We introduced a PC-based program to improve the quality of the low contrast portal images. It can be used easily and has no high cost. But still as, a verification tool can decrease the uncertainty of radiation treatments[11-13]. The importance of the subject is that the dose- response curves for treatment of malignancies profoundly show a strict margin in virtual 100% tumoricidal dose and normal tissue complication[14]. The results of both types of the analysis proved that our program is able to improve the quality of the image (figure 2). So, it can be useful for treatment planning specially for the centers that are not able to spend high prices for EPID.

Correcting treatment field via portal film could increase radiation accuracy. Daily electronic portal imaging reported dramatically to improve the precision of EBRT in the treatment of patients[3].

However, poor spatial and contrast resolution of the portal images are serious problems and may prevent its routine usage during radiotherapy. Since, portal images are formed by projections of anatomical structures in the path of the radiation beam, they have poor quantum efficiency. The image is recorded by placing the receptor in the exit path of the beam.

Poor quality of the portal images (in comparison to the radiology images) is related primarily to the high energy of the incident photons. It leads to the increase of scattered photons via the Campton interaction which decreases the differential absorption within the irradiated volume[15-17]. Also, there are other factors which contribute to the low contrast of the image such as lack of devices to control or eliminate the scattered photons. In addition, the patient motion either voluntary or involuntary, and the size of the irradiation source due to geometrical status are the major causes of the image obliteration.

The histograms of the images show the frequency of the gray levels in spatial domain (figure 2 c, d). Our program works mainly on this property of the image, so that, the lower and the higher gray levels are contributed to the histogram to produce a long scale contrast on the final image. In histogram of images horizontal axis is the probability of the image gray levels that are clearly specified (from black to white). The horizontal axis on the other hand, is describing the image density. Vertical axis is describing various pixels of each gray level and in fact is providing us with information about the intensity of density in each point of these images. Just as we observed in the primary images, all pixels of images are located near the center of gray level, and therefore images are not very transparent. Distribution of pixels of the images in various densities is very widespread and results in an image with unique quality[18].

The contrast resolution in the resultant image increases the soft tissue differentiation. Different methods have been reported for contrast improvements. Contrast enhancement by CLAHE uses the global histogram equalization method of enhancing the display of images by giving each pixel in the image a new intensity proportional to its rank in the image intensity histogram[19]. This flattens the histogram (every intensity occurs with equal probability) and is intended to optimize the display of information in the image. Global histogram equalization methods fail due to very sensitive human visual system to local contrast in a scene and are relatively insensitive to absolute luminance or to spatially separate relative luminance.

Adaptive contrast enhancement methods offer improvements over global methods since the contrast of a pixel is modified based on its local, spatial neighborhood. In adaptive histogram equalization (AHE), a pixel is assigned an intensity based on the histogram of its spatial context[20]. The local neighborhood region which is analyzed to assign a new intensity value to a pixel is called the "contextual region". A commonly used contextual region for a pixel is a rectangle centered at the pixel's location. The shape and size of the rectangle remain fixed for all the pixels in the image.

The purpose of contrast enhancement by SHAHE method is to make objects visually distinct. For this purpose, it makes sense that the contextual region of a pixel to be sensitive to the shape of the object in which it is contained and to the shape of nearby structures. But, this method is insensitive to object shape tend to create artifacts which degrade the edges.

EPIDs can acquire digital portal images using a very short exposure while the patient is treated, with minimal consumption of personnel time and other resources. They can produce images with high quality comparable to radiographic images(19). Different types of detectors like phosphor screens(21), ion chambers(22), and solid state matrices(23, 24) have been used for these devices. In addition to the problems of cost, they introduce new problems associated with the management of the large number of digital images and associated patient information, and with the timely analysis of each image.

A portal imaging verification system was developed in the visual C++ integrated environment under Windows 95 operating system(25). Our program was run in MATLAB environment and is compatible with Windows XP with minimum system requirements.

The main disadvantage of our presented work is that uses the portal film and needs film processing facilities. This procedure is time consuming and may not be applicable for on-line treatment set-up error correction. The overall procedure time needs about 30 minutes for each patient.

CONCLUSION

Since radiation oncologists believe that final images have a higher contrast, and from the statistical assessments it can be concluded that an increase of average numbers and deviation of images value will increase the contrast. As a result processed images via this program will lead to have a higher diagnostic ability. Superiority of final images within three studied parameters by the experts (superiority of lung image, superiority of thorax and its soft tissue images) can be used to increase the accuracy of the treatment set up and decrease the probability of normal tissue complications.

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