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Portal image contrast enhancement

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Summary

Aim The delivery of radiation doses to the target volume, while minimizing the dose delivered to normal tissues, is the main objective in radiotherapy. The intention in our study was to enhance the contrast of portal images, in order to increase the accuracy of delineation of the organs in the irradiated field.

Materials/Methods Software was written, based on local enhancements to the pixel values in the image matrix. Portal images were digitized by CCD and stored in a format compatible with this program.

We applied this program, as an m-file in a MATLAB imaging tool box, to the matrices of the portal images. The imaging parameters, before and after application of the program, were compared.

Results Quantitative information was obtained from images. Analysis of the means, and standard deviations, of these data showed that the differences between criteria in the two groups of images were significant ($p<0.01$). In the case of the qualitative analysis, final images scores were based on "special weight ". The result of this test confirmed the superior quality of the post-processed images, from the professional point of view.

Conclusion The superior final images, as judged by experts using three studied parameters (superiority of lung images, superior images of the thorax and its soft tissue), can be used to increase the accuracy of the treatment set up and therefore decrease the likelihood of complications in the normal tissues.

Key words **contrast enhancement • radiotherapy • portal imaging • MATLAB • imaging tool box**

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Background

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

Verification of the treatment field and quality control are essential steps in the treatment procedure, in order to decrease the overall uncertainty to an acceptable level with the available equipment. Many sources of errors exist, including positioning and accuracy in directing the beam so as to ensure precise coverage of the target volume. This may represent the greatest source of error, especially in machines not equipped for tele-radiotherapy. Positioning errors result in both under-dosage of the target volume and unnecessary irradiation of the normal tissues, leading to a decrease in the probability of local tumour control and an increase in normal tissue complications. Thus, the verification of field alignment, using portal films, can increase accuracy by identifying localization errors. It has been reported that a significant reduction in localization errors can be achieved by increased use of portal films [3–5]. As conventional portal films remain the only routinely available technique in most centres, its disadvantages, such as poor image contrast, time-consuming processing and high costs, make its frequent use impractical. The most advanced radiotherapy machines are equipped with real-time electronic portal imaging devices (EPID) to verify whether the irradiated volume is confined to the target volume or not [6–8]. Another increasingly important application for portal imaging systems is on-line dosimetry verification [9], though the high cost of such equipment means that very few centres are able to use this facility.

Aim

In this paper we present a PC based software solution for contrast enhancements, to improve the quality of chest wall portal images in patients undergoing routine breast radiation treatment.

Materials and Methods

Twenty two patients who had undergone partial or total mastectomy and were presently undergoing tangential irradiation were entered into this prospective study. Of these, 13 patients had undergone conservative surgery and 9 were after total mastectomy.

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

In our department, the approach for irradiation of the chest wall consists of a fixed source-to-skin distance technique, with the patient in semi-supine position on a wedge-shaped breast support and with arms abducted, making the dorsal beam edge run parallel to the sternum. To reduce the amount of lung tissue, and/or the anterior wall of the heart, being 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 an average photon beam energy of 1.25MeV.

To obtain portal images a dedicated cassette holder was tailored (Figure1) in addition to the modification of a regular 24×30cm radiography cassette and medium speed film. The intensifying screens were removed were replaced with a 1mm thick lead sheet on the cassette front. Films were processed using a conventional automatic processor. The cassette holder was positioned so that the image receiver face was perpendicular to the central ray axis and such that the cassette could cover all of the irradiated field area.

A PC based charge-coupled device (CCD model: RAD system – 8 bits per pixel and with a pixel resolution of 640×480) was used to digitize the portal images. The images were saved in the tagged image file format (TIFF), which is compatible with the image processing tool box of version 6.0 of MATLAB. Digital images were obtained for medial, tangential portal films for all 22 patients, resulting in 22 non-digital and 22 digitized images for comparison.

The dedicated portal film contrast enhancement kernel, T, was based on a local enhancement on the neighbourhood pixel method. "T" is a transformation function which operates on the original image function, f, inducing a final image function of g. The transfer function operates in the spatial domain, (x, y), of the 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 passed over the original image matrix. As "T" moves over the original image, it calculates the means and standard deviations of neighbourhood pixels in the image matrix. The algorithm of the program is shown in the following equation:

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

where the A(x, y) and m(x, y) are, respectively, the modified values of the means and the standard deviations of the image matrix. The value of A(x, y) is obtained from:

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

The coefficient, k, is a dimensionless number which can be altered according to the type of image or the desired information. In this project, the value of k was 0.75. The M and $\sigma(x, y)$ are, respectively, the means and variance values of neighbourhood pixels in the image matrix.

After obtaining the original and final images, the pairs were analysed both quantitatively (numerically) and qualitatively (interpretation value). Quantitative analysis was done using statistical parameters consisting of the means and the standard deviations of both pre and post processed images. The difference between the statistical parameters was tested using the Student t-test. Results were considered significant if the p-value was less than 0.05.

Qualitative analysis was performed by means of a questionnaire completed by three radiation oncologists. After processing, the images were scored (0–3) in comparison to the original images, for the visibility of substructures in each image. Finally, the level of the significance of differences between the post-processing scores and the original values (0) was tested by "expert opinion".

Results

We designed and tailored the cassette holder to contain the portal films of patients, during tangential field radiotherapy of the of the chest wall. This adjustable holder could tolerate the weight of a 24×30 radiography cassette.

The image processing program was written in a MATLAB "m.file" (Table 1). This program locally enhanced the image contrast based on Eq. 1, and was designed to be user friendly. It began by inputting the original image, using the "imread" command of the MATLAB environment. The program had three main sections; 1) input – image matrix format correction and introductory prompt, 2) the core of the program – which consisted of the kernel, the calculation of means and standard deviations, the convolution function and the operation of the transfer function on the original image to produce the matrix of the final image (a portion of this section is shown in Table 1), and 3) the output section; which consisted of the images before and after processing, along with their related histograms. The image histograms showed the distribution of intensities in indexed images. In such plots, by making "n" equally spaced bins, each representing a range of data values, the number of pixels within each range could be calculated (Figure 2).

Since images were defined by their standard deviations (Std) and averages (Mean), these data could be sourced from the MATLAB's instructions. Analysis of the mean and standard deviations of the results has shown that the differences between these criteria from the two groups of the images is significant ($p<0.01$).

Qualitative analysis was carried out in order to assess whether the numerical assessment alone could be reliable in judging the superiority of the post-processed images to the pre-processed ones, or not. Since the score of pre-processed images score was "0" by default, final image scores were based on "special weight". The result of this test confirmed the superior quality of the post-processed images from the professional point of view.

Discussion

We introduced a PC-based program to improve the quality of low contrast portal images. It can

Table 1. A portion of the second section of the program showing the calculation of standard deviations and the main operation.

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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(avg9/8);
    %(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
```

be used easily and does not involve high costs. Used as a verification system, it can decrease uncertainty in radiation treatment [10–12]. The importance of this subject is related to the strict margin between the nearly 100% tumouricidal dose and normal tissue complications shown in dose-response curves [13]. The results of both types of analysis showed that our program is able to improve the quality of images (Figure 2). This means that it can be useful in treatment planning, especially in the centres that lack the resources to purchase EPID.

Correcting the treatment field through use of portal films may increase the accuracy of irradiation. Poor spatial and contrast resolution of

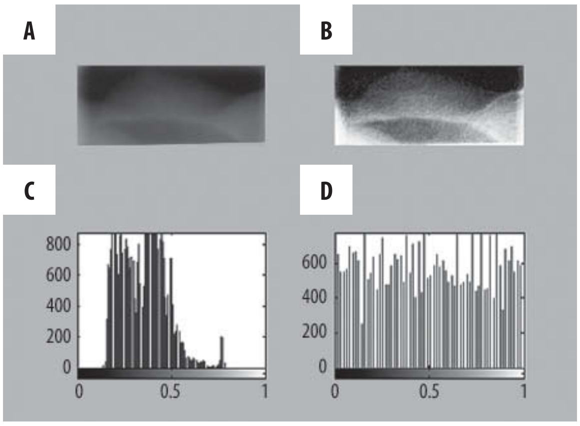

Figure 2. The input and output of the program. (**A**) original portal image, (**B**) post-processed image, (**C**) the histogram before processing and (**D**) the histogram after processing.

portal images is a serious problem however, and may prevent routine use of these films during radiotherapy. Portal images are formed by projections of anatomical structures in the path of the radiation beam. The image is recorded by placing a receptor in the exit path of the beam.

Poor quality of portal images (in comparison to radiology images) is primarily related to the high energy of incident photons. This results in increased scattering of photons, by a process known as the Campton interaction, which in turn decreases differential absorption within the irradiated volume [14–16]. Other factors also contribute to the low contrast of images, and this includes the lack of devices to control or eliminate photon scatter. Additionally, the size of the irradiation source (geometrical status) and voluntary or involuntary movements on the part of the patient, are major causes of image degradation.

Image histograms show the frequency of grey levels in the spatial domain. Our program mainly works on this property of the image, such that lower and higher grey levels are added to the histogram in order to produce a long contrast scale on the final image. In the histograms, the horizontal axis represents the frequency of specified grey levels (from black to white). The horizontal axis also describes image density. The vertical axis describes individual pixels at each grey level and provides us with information about the degree of of density at each point of the images. We observed, in the primary images, that all the pixels were located near to the central grey level meaning that the resulting images are of poor transparency. The distribution of pixels in the processed images, at various densities, is widespread, resulting in images of unique quality [17].

As the contrast resolution in the processed images increases, so the differentiation of the soft tissues improves. Various methods have been reported for contrast improvements. Contrast enhancement by CLAHE uses the global histogram equalization method, enhancing the display of images by giving each pixel in an image a new intensity proportional to its rank in the image intensity histogram [18]. This procedure effectively flattens the histogram (every intensity occurs with equal probability) and is thus intended to optimize the display of information in the image. Global histogram equalization methods fail because the human eye is very sensitive to local variations in the contrast of a scene and is relatively insensitive to absolute luminance, or to spatially separated relative luminance levels.

Adaptive contrast enhancement methods offer improvements over global methods since the contrast of a pixel is modified based on its local, spatial neighbourhood. In adaptive histogram equalization (AHE), a pixel is assigned an intensity based on a histogram of its spatial context [17]. The local neighbourhood region, which is analysed to assign a new intensity value to a pixel, is called the “contextual region”. A commonly used contextual region for pixels is a rectangle centred on the pixel’s location. The proportions of the rectangle are constant for all the pixels in the image.

The purpose of contrast enhancement, by the SHAHE method, is to make objects visually distinct. For this purpose, it makes sense that the contextual region of a pixel should 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 and tends to create artefacts which degrade the edges.

EPIDs can acquire digital portal images, using very short exposures, while the patient is being treated, with minimal consumption of personnel time and other resources. Different types of detectors, such as phosphor screens [19], ion chambers [20], and solid state matrices [21,22] have been used for these devices. In addition to the problems of cost, they also introduce problems associated with the management of large numbers of digital images, the associated patient information, and with the timely analysis of each image.

The main disadvantage of the work we have presented here, is that it used portal films which require film processing facilities. This procedure is time consuming and may not be suitable for on-line error corrections to treatment set-ups. The overall time required for the procedure was around 30 minutes for each patient.

CONCLUSIONS

Since radiation oncologists believe that final, post-processed, images have a higher contrast, and based on statistical assessments, it can be concluded that an increase in the means and standard deviation values of images will increase the contrast.

Images processed by the program were judged to be of a higher diagnostic potential. The superior final images, within the scope of the three parameters explored by the experts (superiority of lung images, superior images of the thorax and its soft tissue) can be used to increase the accuracy of the treatment set up and thereby decrease the probability of normal tissue complications.

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