Usability of image fusion: optimal opacification of vessels and squamous cell carcinoma in CT scans

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The purpose of this study was to evaluate the feasibility and usability of digital image fusion of different phases in spiral CT studies of the head and neck. Patients with squamous cell carcinomas underwent dual-phase spiral CT using a contrast material. The images of the early phase were showing optimal vascular enhancement. The images of the late phase were showing optimal tumor conspicuity. Selected images of the early phase were fused with selected images of the late phase by application of user-centered developed software. The image fusion was done in a semi-automatically way on a desktop computer (PC). The relationship between tumors and adjacent vessels was better visualized on the fused images than on the original source images. As a conclusion it can be emphasized, that digital image fusion of early and late phases enabled combined opacification of vessels and squamous cell carcinomas, which facilitated the topographic assessment of the tumors size and spread.

Keywords: medical image processing; usability; image fusion; squamous cell carcinoma; helical CT

Usability bei der Bildüberlagerung: optimale Darstellung von Gefäßen und Karzinomen in CT-Bildern.

Generell sind Radiologen sehr gut trainiert, verschiedene Bilder mental zu vergleichen; dennoch ist dieser mentale Vergleich nicht nur anstrengend, sondern auch schwierig. Aus diesem Grund wurde eine spezielle Software zur Bildüberlagerung entwickelt, die mittlerweile im Routinebetrieb eingesetzt wird. Die vorliegende Arbeit befasst sich mit Fragen der Usability bei der Kombination von durch Kontrastmittel verstärkten Gefäßbildern und Tumorbildern zur besseren und gleichzeitigen anatomischen Darstellung von Gefäßen und so genannten ,,squamous cell-Karzinomen'' in der Hals- und Kopfregion. Bei einer zeitlichen Serie von CT-Aufnahmen einer Region wird ein Kontrastmittel injiziert. Bei den ersten Bildern der Serie werden so die Gefäße optimal dargestellt. Bei den letzten Bildern der Serie ist das Kontrastmittel aus den Gefäßen ausgetreten und wurde zum Teil von den Tumoren aufgenommen. Es wird jetzt jeweils ein Bild vom Anfang der Serie und ein Bild vom Ende der Serie durch Bildüberlagerung kombiniert. Ergebnis: Die computerunterstützte Bildüberlagerung liefert eine bessere anatomische Darstellung von Gefäßen und (squamous cell-) Karzinomen in der Hals- und Kopfregion.

Schlüsselwörter: medizinische Bildverarbeitung; Usability; Bildüberlagerung; Karzinome; Spiral-CT

1. Introduction

In medical image processing, image fusion is a method of combining different kinds of information (for example: morphological and functional information) in *one* image. Image fusion is nowadays a growing field in radiology. By use of images from different modalities the diagnostic information can be improved. Typically, morphological images resulting from CT or MR are fused with functional images like radionuclide studies (*Nicoletti et al., 1993; Wahl et al., 1994; Kagawa et al., 1997; Higashino et al., 2006; Vogel et al., 2005; Brix et al., 2005*). In this study we use images from one CT examination at different time delays. Consequently, the advantage is that identical image acquisition and reconstruction parameters are used for the fusion.

For the interpretation of CT images of head and neck a sufficient opacification of the cervical vessels is necessary. In contrast-enhanced helical CT studies the early scans provide optimal vascular enhancement. On the other hand there is an improved conspicuity of certain head and neck tumors, such as squamous cell carcinomas, on delayed scans when vessel opacification has already decreased (*Harris et al., 1996; Choi et al., 2000; Groell et al., 2001; Halpern et al., 2005*). Images, combining optimal tumor delineation with sufficient vessel opacification, are crucial for therapeutic regimes. A possible method to realize this is the injection of a second bolus during the delayed scanning. Disadvantages of this method include the increasing amount of contrast material, which results in higher costs of the CT examination. Additionally, due to the second injection there is a higher emotional and physical stress for the patient. The aim of this study was to evaluate the feasibility and usability of digital image fusion of early and delayed scans in dual-phase spiral CT of the head and neck in order to allow a better assessment of the tumor-to-vessel relationship.

The access to the images and the transfer to the appropriated places is enabled and facilitated by a PACS (Picture Archiving and Communication System) environment.

The software for the image fusion was developed at the Institute of Medical Informatics, Statistics and Documentation (IMI), Medical University of Graz, where experience in both developing user centred software and usability engineering methods is available

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(*Holzinger et al., 2005; Holzinger, 2005*). The software is currently running as part of the daily routine in the department of Radiology of the Medical University of Graz.

2. Materials and PACS environment

As image acquisition modality one of two helical CT scanner (Somatom Plus 4, Siemens, Erlangen, Germany, and LightSpeed Qx/i, General Electric Medical Systems, Milwaukee, WI) was used for our evaluation of digital image fusion. The images were provided in the DICOM format.

In the department of Radiology the digital image acquisition modalities, the reporting consoles, the archive units and the viewing stations are interconnected in a PACS (Picture Archiving and Communication System), allowing therefore access to the fully digital image information (*Wiltgen et al., 1993; Bauman, Gell, 2000*). The archive enables it to hold the image production of nearly five years online. The PACS is connected with a Radiological Information System (RIS) so that the management of the image archives is done by the RIS.

The distribution of the images to selected places within the hospital is initiated either manually by the requester or automatically by a routing function (as part of the PACS-RIS interface). The user has access to the images via PACSview stations (based on PC), which are connected to local databases (image boxes) on special servers.

A PC for image processing purposes is connected to the system allowing access to the image boxes on the servers. The software for image fusion, which is running on this PC, was developed with the ''Interactive Data Language'' software tool (*IDL 5.4, Research Systems, Boulder, CO*).

3. Work flow

In this study we concentrated our interest on patients with primary or recurrent squamous cell carcinomas of the head and neck. All the examinations were performed in a helical mode with a slice thickness of 3 mm (Somatom Plus 4) respectively 3.75 mm (LightSpeed Qx/I). 1.5 was used as pitch factor. The patients underwent dual-phase spiral CT examinations where 100 ml of non-ionic contrast material (Ultravist, iopromide 300 mg I/ml, Schering, Berlin, Germany) was used. The scans of the early phase started 30 s and the scans of the late phase 3–5 min after the contrast material injection. No additional contrast material was administered for the late scans. After the image acquisition the images were reviewed on a reporting console (Sienet Magic View, Siemens) and stored in the optical archive.

The examinations were retrieved via the RIS and transferred to one of the image boxes, where the corresponding image pairs from early and late phase of the CT examination were manually selected at the PC.

Subsequently the image of the early phase (showing optimal vascular enhancement) and the image of the late phase (showing optimal tumor conspicuity) were fused semi-automatically on the PC.

4. Method

The platform of the image fusion software on the PC consists of a graphical user interface with virtual buttons and sliders, which are manipulated by using a mouse (Fig. 1). The system works with images in the DICOM format and therefore all necessary information in the image header is available for image display and processing. The image processing can be done interactively by use of buttons and sliders. Fixed window values can be selected. Additionally there exists the possibility of selecting and changing the window values manually. The fused image can be archived either as digital image and transferred to a viewing station (for example in the surgery) or it can be printed, because there exists the possibility of making hard copies (paper print).

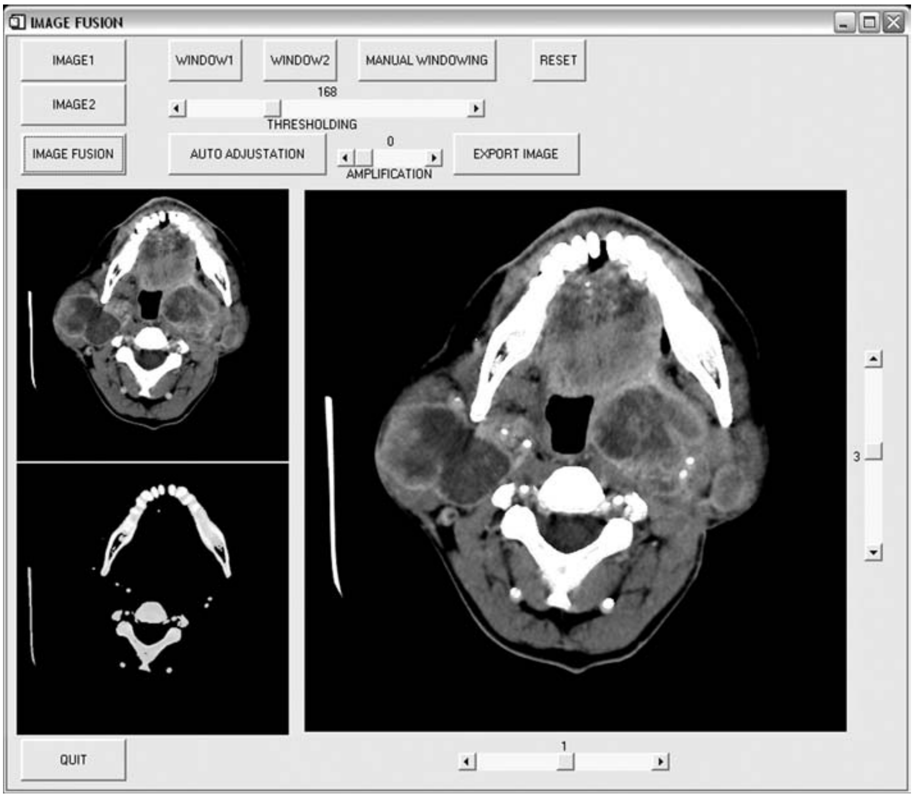

Fig. 1. Image fusion platform for CT images. The thresholded early image and the delayed image are simultaneously displayed with the (larger) fused image

At the beginning of the image fusion session, the image of the early scan and the image of the delayed scan were simultaneously displayed on the PC (with a matrix size of 256 × 256 pixels). In a first step, the vessels and bones are extracted from the early scans using a single threshold algorithm (*Wiltgen, 1999*). The threshold value of the gray levels can be selected interactively by the reviewing radiologist. To extract bones and vessel structures from the early scans a threshold of approximately 140 – 170 Houndsfield units was used. Then these thresholded images were digitally fused with the images of the delayed scans. The fused image has a resolution of 512 × 512 pixels. Image fusion was realized by following logical operation: if the gray level of a pixel in the early scan was above the threshold, then this pixel value was inserted into the fused image; if the gray level of a pixel in the early scan was below the threshold, then the corresponding pixel value of the delayed image was inserted.

$$b_F(x,y) = \begin{cases} b_{\text{early}}(x,y); & |b_{\text{early}}(x,y)| \geq T \\ b_{\text{delay}}(x,y); & |b_{\text{early}}(x,y)| < T \end{cases} \qquad (1)$$

where $B_F = (b_F(x,y))$ is the fused image, $B_{\text{early}} = (b_{\text{early}}(x,y))$ is the early image, $B_{\text{delay}} = (b_{\text{delay}}(x,y))$ is the delayed image and T is the threshold value.

Patient motion resulted in parallel shifting of bony and soft tissue structures between the early and late scans. Such possible patient motion between the early and delayed scans was recognized by shifting of bony structures that were clearly visible on the thresholded and on the late scans. This was corrected manually allowing a linear pixel shifting in the *x*- or *y*-axis, respectively.

The shifting never exceeded 6 pixels, with a pixel size of 0.4 – 0.6 mm. By aligning the bones, other structures such as tumors and vessels were aligned simultaneously. No significant motion occurred in the *z*-axis. Automatic adjustment of the images was possible. Then the relative position of the images was changed automatically by shifting one image in the *x*- and *y*-axis over a distance of a few pixels. In every position the images were subtracted and the minimum value of the subtracted images was selected to detect the maximum overlapping of the two images.

After the fusion of the images, the fused image was displayed together with the original source images.

5. Results

Digital image fusion of early and late scan sequences was easy to perform with the developed software which was specially suited to the needs and requirements of the end-users. It was possible for each patient within a time span of ten minutes per patient. To evaluate the feasibility and usability of the method a study set of eight patients was selected. The study population consisted of seven men and one woman who were 47 to 86 years old with biopsy-proven squamous cell carcinomas. The quality of vessel opacification and tumor delineation in the fused images was evaluated by two radiologists and compared with the images of the early and delayed scans. On both early and delayed scans, as well as on the fused images, the quality of vessel opacification and tumor delineation was determined separately according to a three-step scoring system: good (1), medium (2) and poor quality (3). The results were compared using a paired student's *t*-test.

It was interesting to notice that vessel opacification was better graded in the images of the early scans than on the images of the later scans (1.1 ± 0.3 versus 2.6 ± 0.5, $p < 0.01$) and tumor delineation was poorer on the early scans than on the delayed scans (2.5 ± 0.5 versus 1.6 ± 0.5, $p < 0.05$).

However, on the fused images, the quality of vessel opacification (scored as 1.25 ± 0.4) was not statistically different from the quality of the early scans, but better ($p < 0.01$) than for the delayed images. The quality of the tumor delineation was not lower on the fused images (scored as 1.8 ± 0.4) than on the images of the delayed scans but better than the scoring for the early scans ($p < 0.01$). The relationship between tumors and adjacent vessels was better visualized on the fused images than on original source image.

For the physician primarily the fused image is of special interest. Especially in the case of potential respectability, the assessment of the tumor-to-vessel relationship is of fundamental importance for the surgeon. Because the image fusion software is integrated in a PACS, the image fusion can now be done as part of the routine work in the radiological department.

6. Discussion

Image fusion of the early and delayed scans resulted in simultaneous opacification of vessels and tumors in all examined patients. The results confirmed the synergetic effects of image fusion. Radiologists are generally trained to merge different images mentally by comparing follow up studies of the same modality. However, such mental image fusion may be difficult for physicians who are not familiar on digital images. Nevertheless, for the physician the information of the tumor-to-vessel relationship is very important to plan therapeutic regimen. In these cases the considered fused images might be particularly helpful. Due to the fact that the image processing PC is integrated in the PACS environment, the fused images can easily be transferred via network to the surgery, allowing a planning of the operation at the appropriate place. For documentation purposes our experience shows that a paper print-out of the fused image is of sufficient quality.

Our study was performed with selected patients. The results of our study can certainly not be generalized for every patient who undergoes multiphase CT examinations. However, the study shows that image fusion of different phases of helical CT examinations is of value to physicians reviewing the studies.

7. Conclusion

This study shows that digital image fusion of early and late phase of helical CT examinations enable combined opacification of vessels and squamous cell carcinomas, facilitating the topographic assessment of the tumors size and spread. Such fused images might be particularly helpful for physicians who need the information of the tumor-to-vessel relationship for therapeutic purposes.

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