Coregistration of Brain Single-Positron Emission Computed Tomography and Magnetic Resonance Images Using Anatomical Features

Lucas Ferrari de Oliveira and P.M. Azevedo Marques

The present report describes a computer tool for the coregistration of single-positron emission computed tomography (SPECT) and magnetic resonance (MR) images to aid the diagnosis. Two types of images are used for some neurologic diseases: one of them anatomic (magnetic resonance) and the other metabolic (SPECT), with the specialist being required to make a mental integration of the examinations. This procedure can be improved by using a computer tool that might permit the presentation of this information in a single image. The coregistration is performed on the basis of pairs of points positioned by a specialist according to the structures present in the images and the least squares error is calculated between them using Euclidean distance. Coinciding planes and section thickness are selected for the two modalities and the SPECT image is processed so as to have the same spatial resolution as the resonance image.

Copyright © 2000 by W.B. Saunders Company

IMAGE REGISTRATION is the alignment of two or more image volumes in the same geometric space; hence, these voxels in the same anatomic location can be directly compared. Image coregistration is the term used to denominate the alignment of image volumes with different modalities (eg, single-positron emission computed tomographic (SPECT) and magnetic resonance imaging [MRI]).¹

Variations of blood flow in the ictal period (during a seizure) are related to the region of the brain related topographically to the epileptic foci.² These variations can be evaluated by SPECT examination, which provides a functional image of the brain. SPECT does not have a good spacial resolution, whereas MRI provides structural and anatomic information. Generally, specialists have to mentally perform the integration of these two image modalities.

From the School of Engineering of São Carlos and the Medicine School of Ribeirão Preto, University of São Paulo, Brazil.

Supported by FAPESP process no. 98/12589-7.

Address reprint requests to Lucas Ferrari de Oliveira, Av. Café, 1715—Apto. 112, CEP 14.050-230, Ribeirão Preto, São Paulo, Brazil. E-mail: lferrari@cci.fmrp.usp.br.

Copyright © 2000 by W.B. Saunders Company

0897-1889/00/1302-1049\$10.00/0

doi:10.1053/jdim.2000.6880

Lately, a large number of image fusion techniques and tools have been developed.²⁻⁸ All of the coregistration techniques intend to calculate a transformation matrix to convert the coordinates of a volume in the space of another. In some coregistration techniques, the image volumes are considered as a rigid body with linear connections among all the voxel dimensions.¹

The objective of our study was to create a new tool that can perform the integration of the SPECT and MRI examinations. As no changes in the working routine to obtain the images were necessary, the technique can be applied to previously acquired images.

Our system uses two slices from the volumes, both being at the same height and having the same width. The slices on both images are made by specialists, taking into consideration which is the best region for analysis.

MATERIALS AND METHODS

All patients were submitted to long-term video-electroencephalogram (EEG) monitoring and structural (MRI, CT) and functional neuroimaging (ictal and interictal SPECT) as part of the routine evaluation for epilepsy.

The tracer for SPECT, ^{99m}Tc-ethyl cisteinate dimer (ECD), was injected during video-EEG, at maximum dose of 1,295 MBq (35 mCi), as soon as the seizures started. Scans were acquired preferentially within 2 hours after the injection, with a single-head Siemens (Chicago, IL) Orbiter gamma-camera, 64 frames in 360 degrees, matrix 64 × 64, low-energy, high-resolution (LEHR) collimator. Images were processed with attenuation correction (Chang first order) and Butterworth Filter 4.25 (Sophy Medical Vision America, Ohio), and reconstructed as transaxial sections parallel to orbitomeatal line, from which perpendicular frontal and sagittal sections were produced. SPECT scans were blindly and independently analyzed by two observers. Interictal injection was performed in the supine patient, while in a dark and quiet room.

The MRI images were acquired in a 1.5 T magnet (Siemens Magnetom Vision), using gradient-echo sequence (145 partitions) in the sagittal plane. The images were then reformatted by multiplanar reformatting (MPR) to the axial and coronal planes to comply with the SPECT orientation.

The equipment used for the system development is a personal computer (Pentium II [Intel], 400 mHz, 128 Mbytes RAM, and a 17-inch monitor). The operational system used is the Linux RedHat 6.0 (RedHat Software, North Carolina). To develop the user's graphic interface, we employed the Tcl/Tk 8.0 language, with the process made in C language. The combination of these two languages provided good equipment performance.

The method uses seven markers that must be positioned by a specialist in both images (Figs 1 and 2). The association of the markers is made through its shape; each marker in one image has its correspondent in the other image. A determined anatomic position is related its marker. The positioning of the markers must be done using anatomic regions as commissura anterior, commissura posterior, corpus callosum and thalamus. If these structures are identified on both images, they will serve as a reference for the marker's positioning. If such structures were not identified, alternative landmarks were used in both images.

After the anatomic positioning of the markers, the calculation of the error of points distance is done. Initially, the Euclidian distance⁹ between its coordinates is measured (equation 1: Euclidian Distance Formula):

$$D = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

Where x_1 and x_2 are the coordinates of x and y_1 and y_2 are the coordinates of y in images 1 and 2, respectively. All seven pairs of markers have their correspondent distance calculated, and the quadratic error¹⁰ of the points is measured (equation 2: Quadratic Error Formula):

$$\text{Error} = D_1^2 + D_2^2 + D_3^2 + D_4^2 + D_5^2 + D_6^2 + D_7^2$$

Where $D_1, D_2, D_3, \dots, D_7$ are the Euclidian distances calculated

between the pairs of markers. After the initial *error* calculation, all markers are translated, with one of them being the "real marker." The real marker will be the "pivot marker" and the operations will be related with it. The pivot marker coordinate is (x,y) ; its pair will make a corresponding translation from $(x-3, y+3)$ to $(x+3, y-3)$, passing through the point (x,y) and covering an area known as neighborhood 7×7 of the pixel (x,y) (Fig 3). The same process is applied, so that translation will be done in all points.

After each translation of the markers, the total error of the group is measured and if the *error* presented in the real position is smaller than the previous *error*, the real *error* value substitutes the previous *error*, and the pivot marker and the markers' translation are recorded. The smallest *error* found, after all translations being considered, is regarded as the best curve fitting of the markers. After the end of the process, with this information, the program works upon the whole image applying the translation, in all points that belong to it.

The image fusion process is performed after the last stage. An edge detection is made by the Sobel algorithm⁹ in the MRI and this processed image is subtracted from the SPECT image to locate the epileptic foci (Fig 4). The resultant image is visualized in color scale. In this presentation, the image quality is poorer than real, considering that it is in grayscale.

Fig 1. Resonance image with markers.

Fig 2. SPECT Image with markers.

DISCUSSION AND CONCLUSION

The coregistration of anatomic and functional images is of great importance in the evaluation of epileptic patients. A description of a technique that uses anatomic markers and performs the image coregistration of SPECT and MRI was made. This technique can also be adapted to the use of CT.

The image obtained from the fusion of the other two images might have a 1-pixel error, with this pixel being considered the size of the pixel of the

Fig 3. Pivot marker neighborhood 7×7 .

Fig 4. Image after fusion process.

image with the smallest resolution (in our case, the SPECT). This difference is clinically insignificant, according to specialists.

The results obtained were satisfactory. The next step is to consider the rotation of the markers to improve the results and also to develop an automatic boundary recognition. Another improvement in the system would be the use of the complete

examination volumes for coregistration, and not only isolated and selected slice images.

ACKNOWLEDGMENT

The authors wish to thank the professionals of the Center of Surgery and Epilepsy (Department of Epilepsy) and the Department of Radiology of Hospital of Clinics.

REFERENCES

1. Knowlton RC, Wong STC, Woods RP, et al: Coregistration, in Engel J, Pedley TA (eds): *Epilepsy: A Comprehensive Textbook*. Philadelphia, PA, Lippincott-Raven, 1997, pp 1081-1097
2. Hogan RE, Lowe VJ, Bucholz RD: Triple-technique (MR imaging, single-photon emission CT and CT) coregistration for image-guided surgical evaluation of patients with intractable epilepsy. *Am J Neuroradiol* 20:1054-1058, 1999
3. Pelizzari CA, Chen GTY, Spelbring DR, et al: Accurate three-dimensional registration of CT, PET, and/or MR images of the brain. *J Comput Assist Tomogr* 13:20-26, 1989
4. Shukla SS, Honeyman JC, Crosson B, et al: Method for registering brain SPECT and MR images. *J Comput Assist Tomogr* 16:966-970, 1992
5. Meyer CR, Leichtman GS, Brunberg JA, et al: Simultaneous usage of homologous points, lines, and planes for optimal, 3D, linear registration of multimodality imaging data. *IEEE Trans Med Imaging* 14:1-11, 1995
6. Hill DLG, Hawkes DJ, Crossman JE, et al: Registration of MR and CT images for skull base surgery using point-like anatomical feature. *Br J Radiol* 64:1030-1035, 1991
7. Wahl RL, Quint LE, Cieslak RD, et al: "Anatometabolic" tumor imaging: Fusion of FDG PET with CT or MRI to localize foci of increased activity. *J Nucl Med* 34:1190-1197, 1993
8. Levin DN, Pelizzari CA, Chen GTY, et al: Retrospective geometric correlation of MR, CT, and PET images. *Radiology* 169:817-823, 1988
9. Gonzalez RC, Woods RE: *Digital Image Processing*. USA, Addison-Wesley, 1993
10. Spiegel MR: Ajustamento de Curvas e o Método dos Mínimos Quadrados, in Spiegel MR (ed): *Estatística*. New York, NY, McGraw-Hill, 1972, pp 362-400