Elastic Image Registration Using Correlations

John B. Weaver, Dennis M. Healy, Jr., Senthil Periaswamy, and Peter J. Kostelec

We have developed a multiscale algorithm for elastic registration of images. Rigid registration has many applications but it is often limited by distortions in the images. For example, different views of the same object produce distortions. Common examples of slightly different views producing a distortion can be found in medical imaging, such as matching a current mammogram or chest radiograph with one from a previous year, and in remote sensing, such as matching images taken from different satellite positions. We have developed two methods of elastic registration. Both are multiscale but one used an iterative minimization of the local error and the other uses a windowed correlation. We present preliminary results of the elastic registration method based on windowed correlations.

WE REPORT A MULTISCALE algorithm for elastic alignment of images. The literature is rich with rigid alignment algorithms,[1-9] but there have been relatively few elastic alignment algorithms[10-14] proposed and some require very long computation times. There is a wide array of applications in medical imaging where elastic alignment may be preferable to rigid alignment.

For example, elastic registration is useful in situations where current images are compared to past images to detect changes. This is the case for a significant proportion of all the examinations in Radiology. For example, annual mammograms or chest radiographs are read by comparing the current films to films from previous years. Abnormalities are identified as changes from previous years. However, rigid registration is not capable of compensating for changes in compression in mammography of changes is inspiration level in chest radiographs. Another application of elastic registration is estimating volumes of structures from known libraries. A structure in the brain can be outlined by hand in a reference image set which is then warped to other image sets to find the boundaries of that structure in other studies. The same method could be used to follow tumor volumes as treatment proceeds.

We have been working on elastic registration algorithms that do not require user interaction. Feature matching is difficult from case to case and user interaction is required. So we have used a multiscale algorithm that rigidly aligns smaller and smaller regions of the image.[15,16]

METHODS

Multiscale Registration

Both the image to be registered and the reference image are first scaled down to block sizes of 64 × 64. The rigid rotation and translation parameters are then determined and used to mold the image to be registered. Molding is performed using Bookstein's thin-plate splines.[17-18] The interpolation used B-spline interpolations.[19-20] This first stage constitutes the 'coarsest' scale of the algorithm.

Both images are then divided into four blocks of equal size. The rigid rotation and translation parameters for each block are then determined and used to mold the image to be registered again. The whole process is repeated with further refinements of the blocks until a block size of 8 × 8 is reached. At this scale, it is assumed that rotations are no longer relevant. Only the translation parameters are determined for each block, which is then used to perform the final molding.

Determining rotation/translation parameters

The rotation and translation parameters are determined as follows (Figs 1-3). The input to the routine consists of the two 64 × 64 blocks for which the rigid rotation and translation parameters are to be determined. Both blocks are first filtered using the wavelet based filters. The window that localizes the signal to be correlated should not contribute to the correlation so we window with the scaling function of a wavelet basis and only use the wavelet coefficients of the test image and the reference to determine the alignment. The window can not correlate with other structures in the image and cause a misalignment. The Fourier power-spectra of both blocks are then obtained. The spectra have the property that they are invariant to translations, but have the same rotations as in the spatial domain. Both blocks are then converted to log polar coordinates. This conversion transforms the rotations to vertical shifts. Correlation is then performed and the rotations corresponding to the top 6 correlation coefficients are selected. Note that since we are only interested in the shift along the y-direction, the 1D correlations

From the Department of Radiology, Dartmouth-Hitchcock Medical Center, Lebanon, NH; and Department of Computer Sciences, Dartmouth College, Hanover, NH.

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Address reprint requests to John B. Weaver, Ph.D., Department of Radiology, Dartmouth-Hitchcock Medical Center, Lebanon, N.H. 03756.

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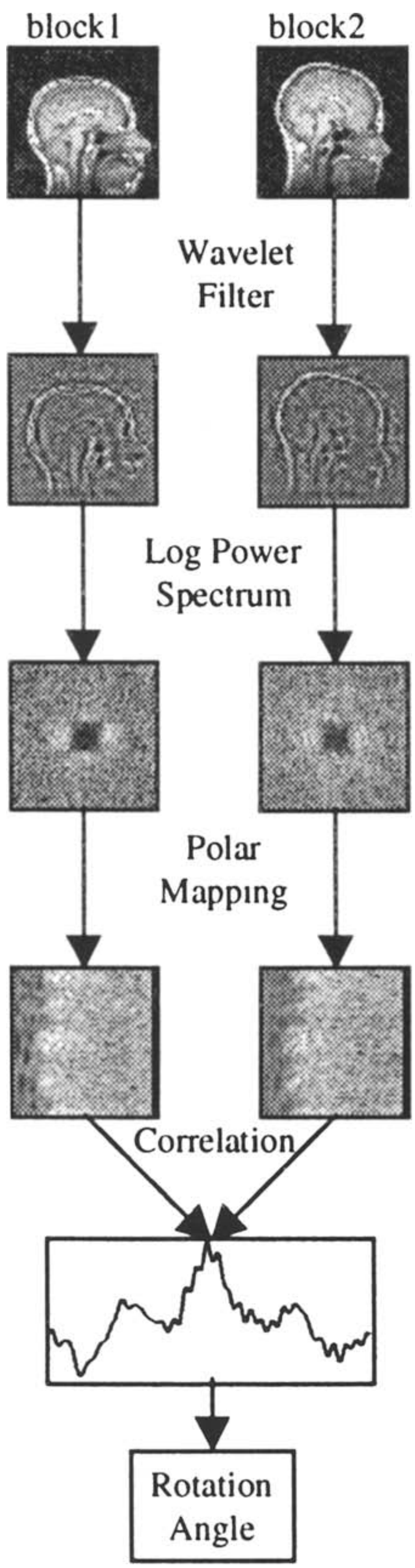

along each row can summed up. Once we determine the angle of rotation, phase-only-correlation is used to determine the translation in both x and y directions (for each of the 6 angles obtained). It should also be noted that there is a 180 degree ambiguity in determining the rotation, so these phase shifts should also be accounted for when determining the translation. Thus in practice, 12 angles (the six selected along with 180 + the six angles) are input to the translation determining routine.

An error measure is then calculated between the reference block and the rotated/translated versions of the block to be molded for each parameter pair. The rotation and translation parameter corresponding to the least error is selected for the molding process.

RESULTS AND CONCLUSIONS

The results of the elastic registration method using windowed correlations are shown for a wide variety of medical images (Figs 4-8). The results are very good. There are no gross misalignments in the images even though the images are of different patients and have different structures in them. For example, in Fig 7 the signal from the fat in the skull is very different in the two sagittal images; the test image has essentially two white bands and the reference image only has one white band. This has produced problems for our previous methods.[15] There are some small scale misalignments such as the front of the corpus collosum in the sagittal image which does not match exactly. However, the size of structure that is matched depends on how small the final window is. So the misalignment may be reduced by using smaller windows. There are several improvements that could be made because the method is very flexible but the results we have shown are of very good quality. One of the improvements we are working on is using other measures of image matching such as the mutual information to select the correct correlation. The result might stabilize the alignment by selecting the best match even if it is not the maximum correlation.

Fig 1. Method of determining the angle of rotation. The input to the routine consists of two 64 × 64 blocks. The blocks are preprocessed through a wavelet filter. The power-spectra of both blocks are then obtained. The power spectrum is independent of translation and preserves rotation. This is then converted to log-polar coordinates, which converts the rotation into a translation in the y direction. The translation is then determined using correlation, which gives us the angle of rotation. It should be noted that in determining the angle of rotation, there is an ambiguity of 180 degrees, which should be accounted for.

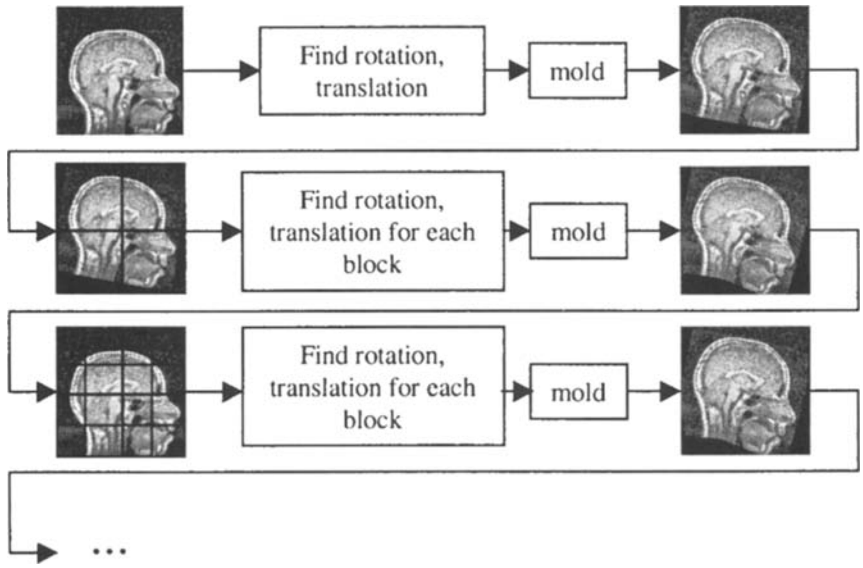

Fig 2. Method of Multi-scale molding. In the first pass of the routine, the translation and rotation parameters for the entire image are determined and are used to mold the image. This molding is a simple rotation and translation of the entire image. This molded image becomes the new image to be molded in the next pass. In the second pass, the image is split into four blocks of equal size. The translation and rotation parameters are determined for each block, and these parameters are fed into the molding routine, which performs the mold. The molding used from this point onwards consists of Bookstein's thin-plate splines. This procedure is repeated with further refinements of the blocks, until a block size of 8×8 is obtained. At this block size, it is assumed that rotations become irrelevant, and thus only the translation parameters are used to obtain the final mold. The figure depicts only the molded image; the reference image is not shown but used to determine the rotation and translation parameters.

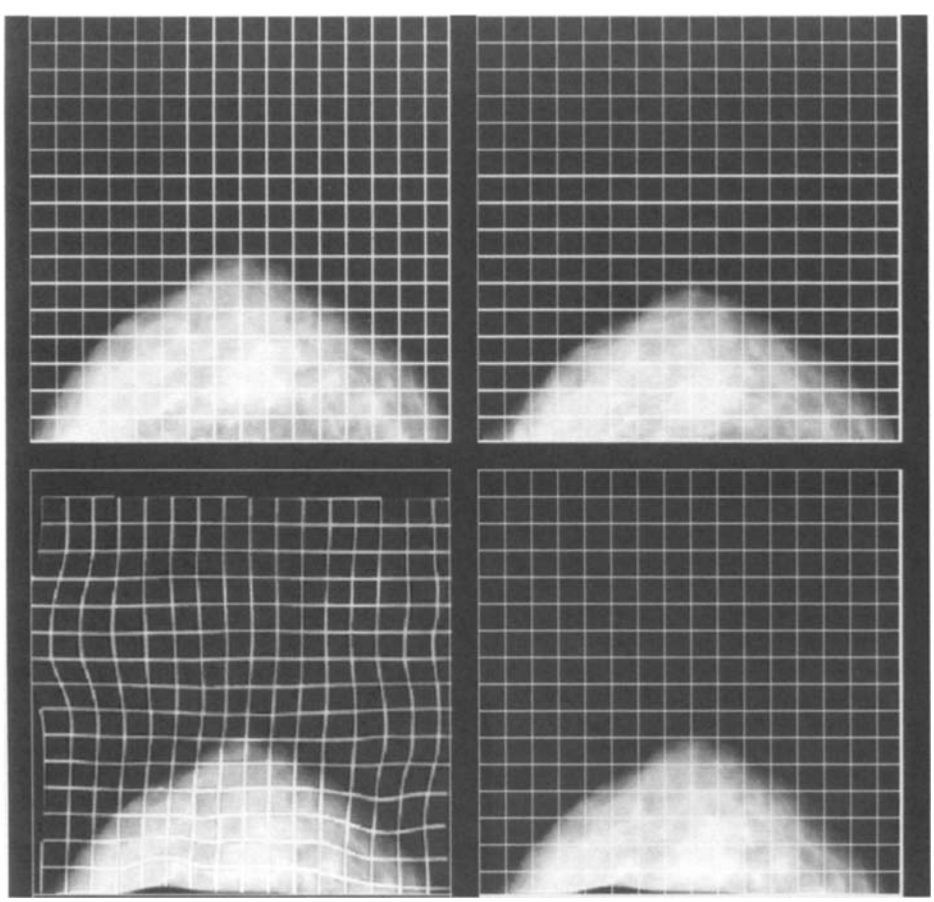

Fig 4. A pair of elastically registered mammograms. The upper left is the test image and the upper right is the reference image. The bottom left is the molded test image with a molded grid superimposed. The bottom right is the molded test image with an unwarped grid so it can be compared to the reference image. The test and reference images are from the same patient taken from the right and left breasts.

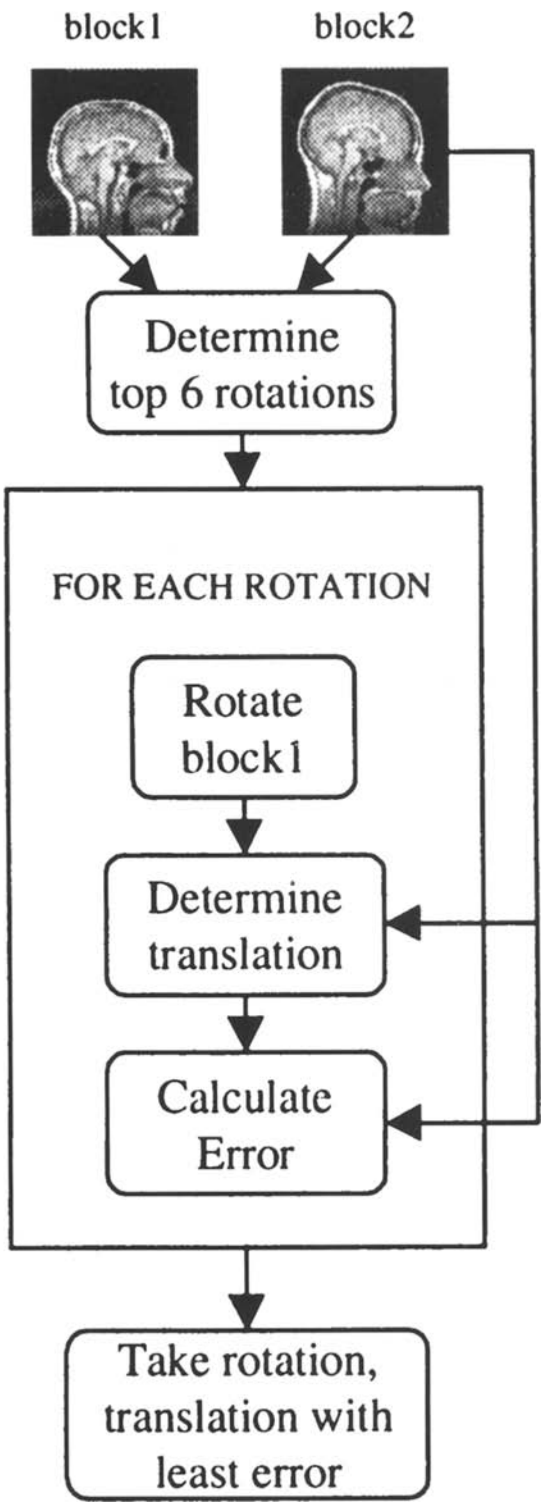

Fig 3. Determination of rotation and translation parameters. In order to obtain the best possible rotation and translation parameters, the following procedure is performed. During the determination of the rotation, the angles corresponding to the top six correlations are chosen. For each of these rotations, block 1 is rotated and the translation parameters are determined using phase only correlation with block 2. An error measure is then determined between the rotated and translated versions of block 1 and the original block 2. The rotation and translation parameter that gives the least error is then selected for the molding.

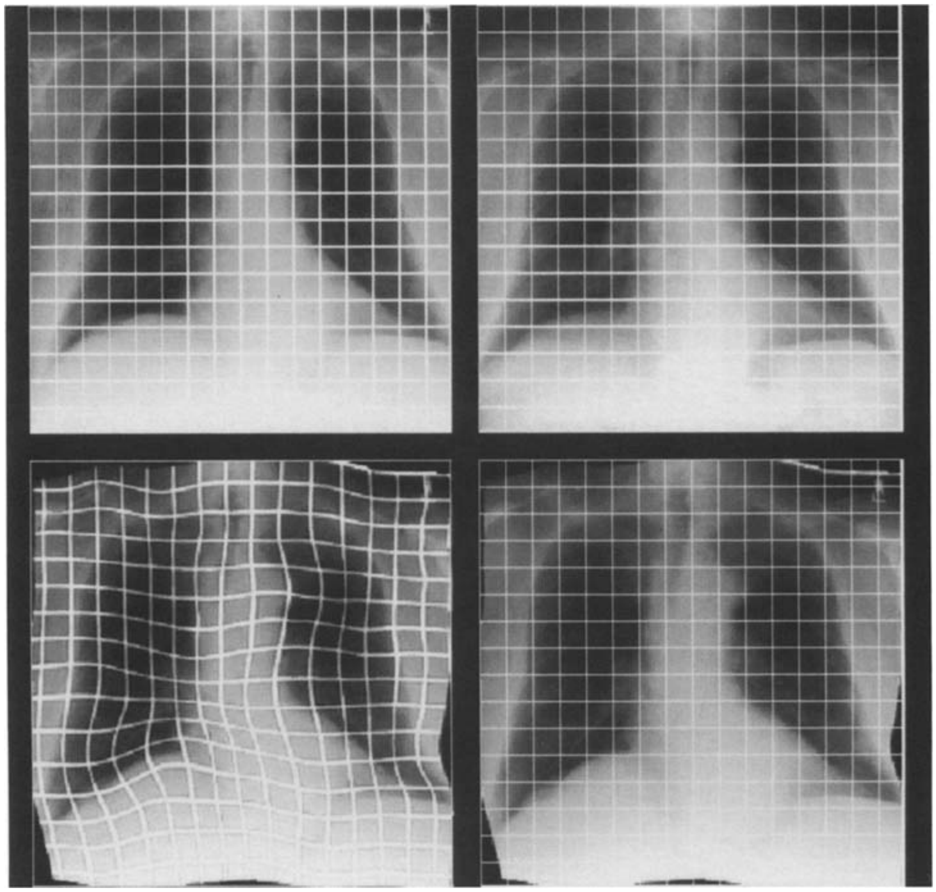

Fig 5. A pair of elastically registered chest images. The images are of the same patient taken one year apart.

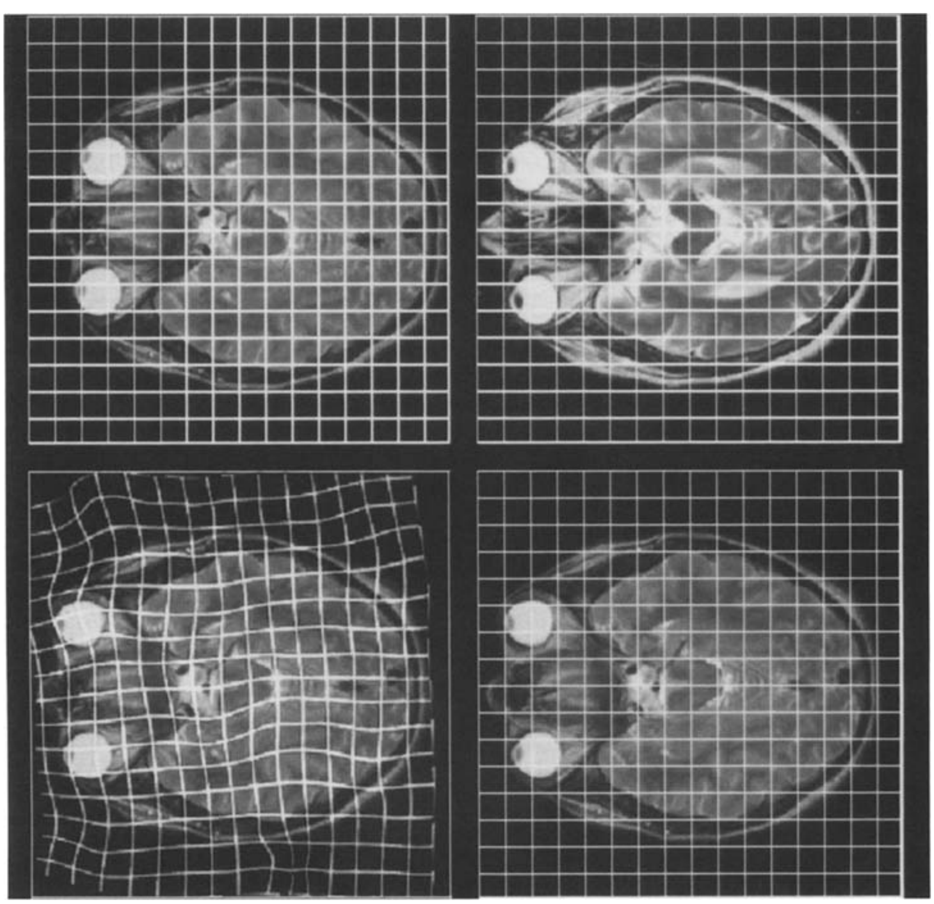

Fig 6. A pair of elastically registered axial MR images. The images are of different patients. The level is only roughly the same.

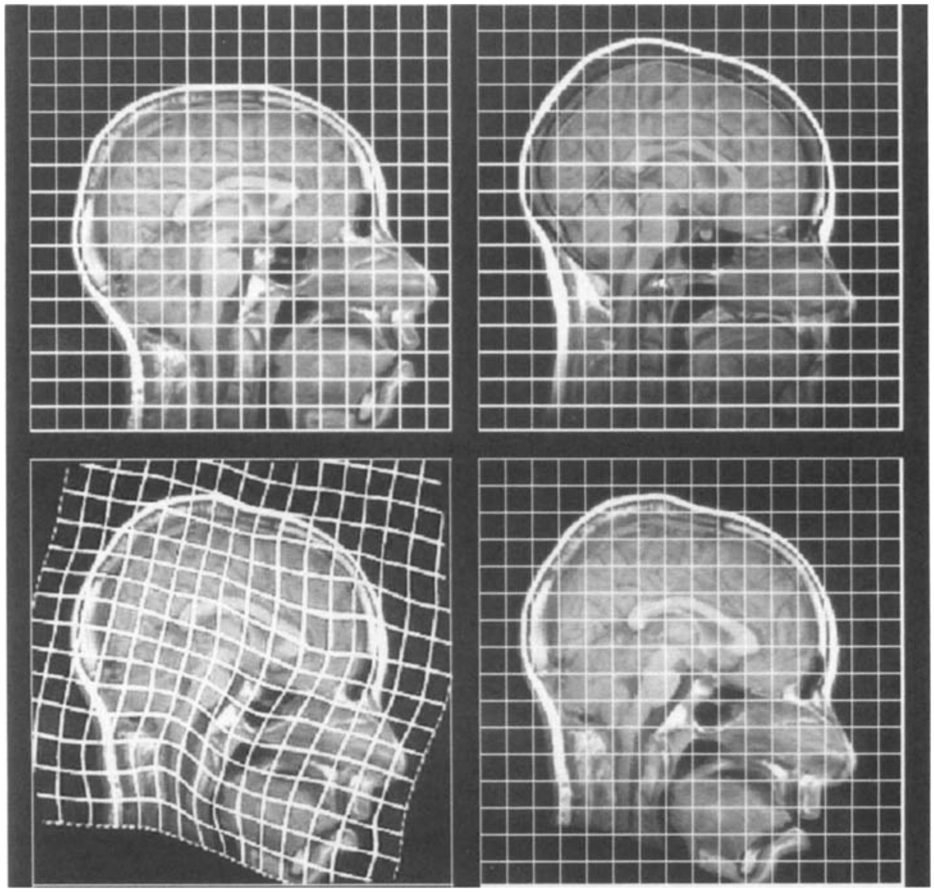

Fig 7. A pair of elastically registered sagittal MR images. The images are from different patients but both are midline sagittals.

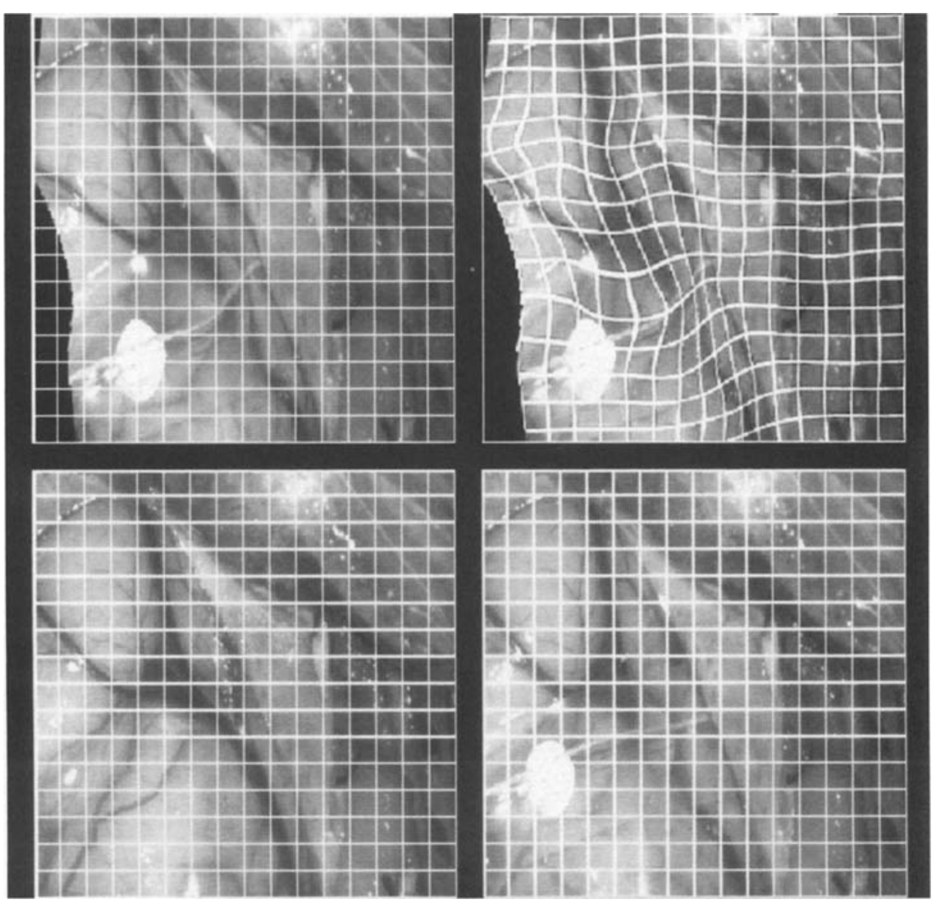

Fig 8. A pair of elastically registered photographs from neurosurgery. The images were taken at different times during a patient's surgery. The brain deforms during surgery due to the pressure of the CSF.

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