

4.5 Results

After the transducer has been calibrated, the spatial information accompanying each image can be employed in many different ways. One way is to combine each video frame with existing images of the same patient, thus providing the surgeon with the ability to complement the information displayed. This idea is explored in section 4.5.1.

Other possible applications demand the composition of the set of video images into a 3-D image of the scanned volume. In order to achieve consistent results, the problem of overlapping regions must be taken into account. We report results for the three transducers in section 4.5.2.

Once the cuberille has been compounded, it may be interesting to try to correct the errors in the position of the transducers, which have produced blurring in the image. To achieve this, we have designed a 2D-3D registration algorithm, developed in section 4.5.3.

Another possible application is to register the compounded volume to existing MR images. We have run for this purpose the algorithm already exposed in previous chapters of this thesis. In section 4.5.4 we report the remarkable accuracy of the result.

Finally, the same 2D to 3D registration algorithm can be applied to register 2D ecography to MR volumes. This procedure could be of relevance to measure intraoperative deformations. We develop it in section 4.5.5.

All results presented in following section were obtained during the second stage in London with our software and hardware (Minibird), except those of section 4.5.1 which were achieved at the first stage and employed the hardware from their site.

4.5.1 Live fusion with MR images of a volunteer

In order to combine the live video with existing MR images we need to link the coordinate system of the MR image to an other related to the patient. To do so, we incorporated a design already studied by a member of our team.

The system, fully described in [11], employs artificial landmarks attached as a block to the teeth of the patient (bite block, BB). Since these landmarks are visible in the MR, they can be segmented and used to calibrate the image to a set of IREDs placed in a fixed configuration. During the intervention, the position of the **BB** is used as the local coordinate system, and the surgeon is able to link the patient to the MR images taken before.

We have designed a first prototype which could link information from both systems. The system grabs the ultrasound image from the device, converts it into the patient coordinate system and computes the equivalent slice in the MR volume. Then, it displays both images on the screen, at a rate of about two frames per second.

We have not fully experimented yet all the capabilities of the system; only a simple scaling in the MR view, which has shown to be extremely useful in the location of the ultrasound image.

We have tested the system on a volunteer. Figure 4.18 shows some results for the nose area and the temples. Actually, the experiment of the volunteer serves solely as a



Figure 4.17: Pictures of a volunteer wearing the bite block

test for accuracy, since for this case images are not very relevant because ecographies can not penetrate the skull.

In a real case, the system could be used to extend the capabilities of the ecographer. The surgeon could check with this modalities the position of any relevant tissue, while at the same time and without any user interaction another screen could depict the corresponding MR slice. This tool would permit the surgeon an easy navigation to areas with poor response to the ecography and thus with little extra effort the resources already dedicated to the operation would be better employed.

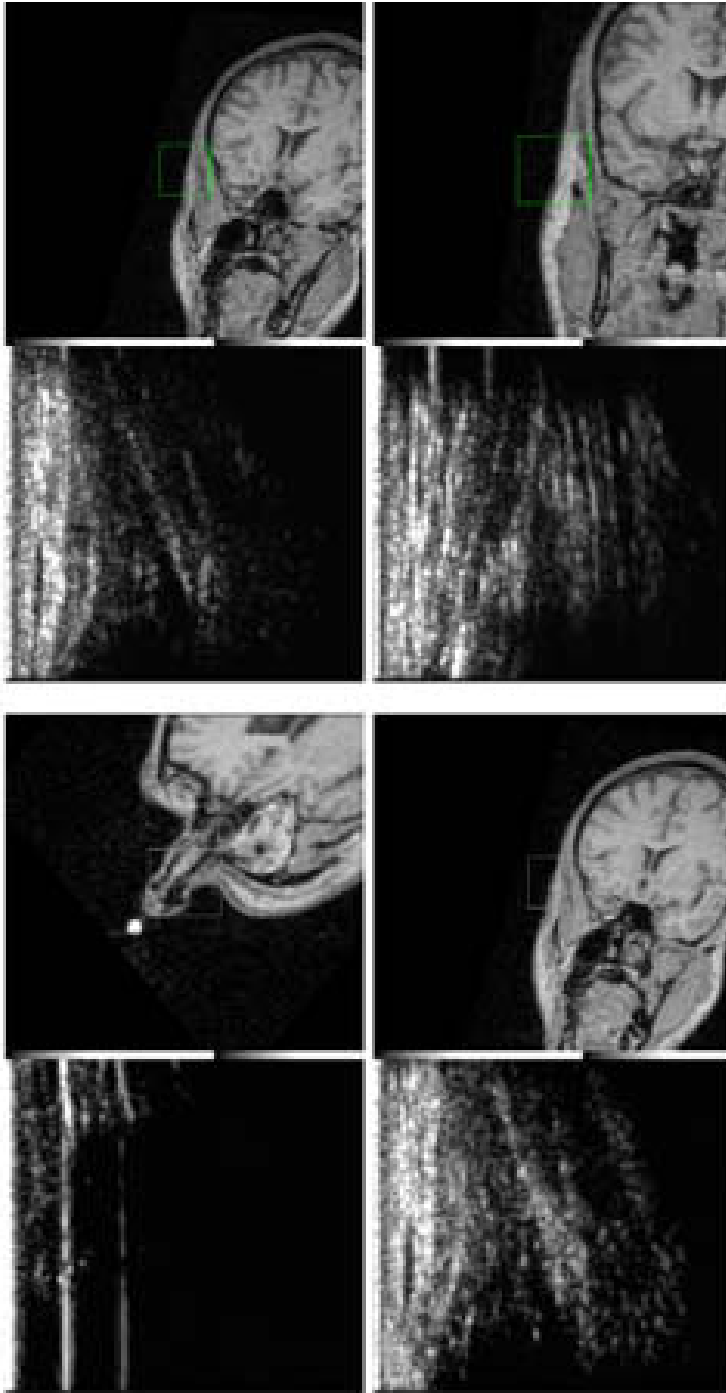


Figure 4.18: Live ultrasound to MR fusion for a volunteer. In each image pair, the left image shows the ecography which corresponds to the region of interest (in a green square) in the right image, extracted from a previous MR volume.

4.5.2 Composition of 3-D volume image of an in vitro human brain

When we designed the project with the ecographies, our final goal was to achieve some estimation of the sinking of the brain which occurs in a neurosurgery operation. This was to be done by mean of a registration with MR images of the brain. As we already reported, this could not be achieved in Barcelona due to lack of the necessary equipment, so the goal had to be adjusted to suit the short time of my stage in London. In addition no surgical operation had been scheduled for that period.

As well, it actually made sense to try other preliminary results before further applications in an operating theatre. In effect, under the pressure of the operation, the time left for errors and trials is very short, or even, because of medical priorities, null. Many times the effort invested produced too little results.

See in figure 4.19 the elements of the system to acquire and compound ecographies. All the elements had been transported personally to London from our site: the laptop, the tracker and the frame grabber. Also, all the software employed was written personally by the author. However, no success would have been achieved without the help and suggestions of the colleagues in the lab, specially my supervisor Dr. Derek Hill, and also Dr. Graeme Penney, Dr. Philip Bachelor and Eddie Edwards, and the computer staff, Collin Renshaw. Also, Dr. Hill generously provided for the scientific suggestions and material means to make the stage feasible. After the suggestions of Dr. Derek Hill, we changed the previous goal of shifting correction and designed an alternative set of experiments to work with an in-vitro human brain. This specimen was borrowed by Dr. Donald Farr, technical manager from the Anatomy, Cell and Human Biology division, at Guy's, King's & St Thomas' School of Biomedical Sciences department, UMDS, University. of London. The in-vitro human brain had to be that of an adult, for we planned to employ the convolutions of the brain for registration purposes.

See a picture of the brain (figure 4.20), and also the MR T1- weighted scanning of this brain. In order to prevent any movement or vibration of the brain, which could produce blurring in the MR image, two sponges were attached to each side, as shown in the pictures. The sponges produced a light pressure which held the object still, making it stable for all the experiments. The specimen was kept in a plastic bucket and covered with conservative liquid, conductive to ecography.

We performed the experiments in this and next sections with three different transducers. We decided to employ the three types in order to see whether there was any difference in results with their varying field of view, pixels size and contrast. Even though the transducer usually employed for intraoperative screening was not available, that with a frequency of 6.5 Hz gave similar results.

Table 4.23 gives the features of the transducers. For all cases, the volume image was not compounded while acquiring the data, but the frames and the position were stored in disk. This procedure is very convenient because it permits further experimentation with the data.

Since we did not compound the volume image on line, we could not assert the full coverage of the area to be scanned; although the swept may have covered the full length, gaps in between the slices could appear. This effect was more important

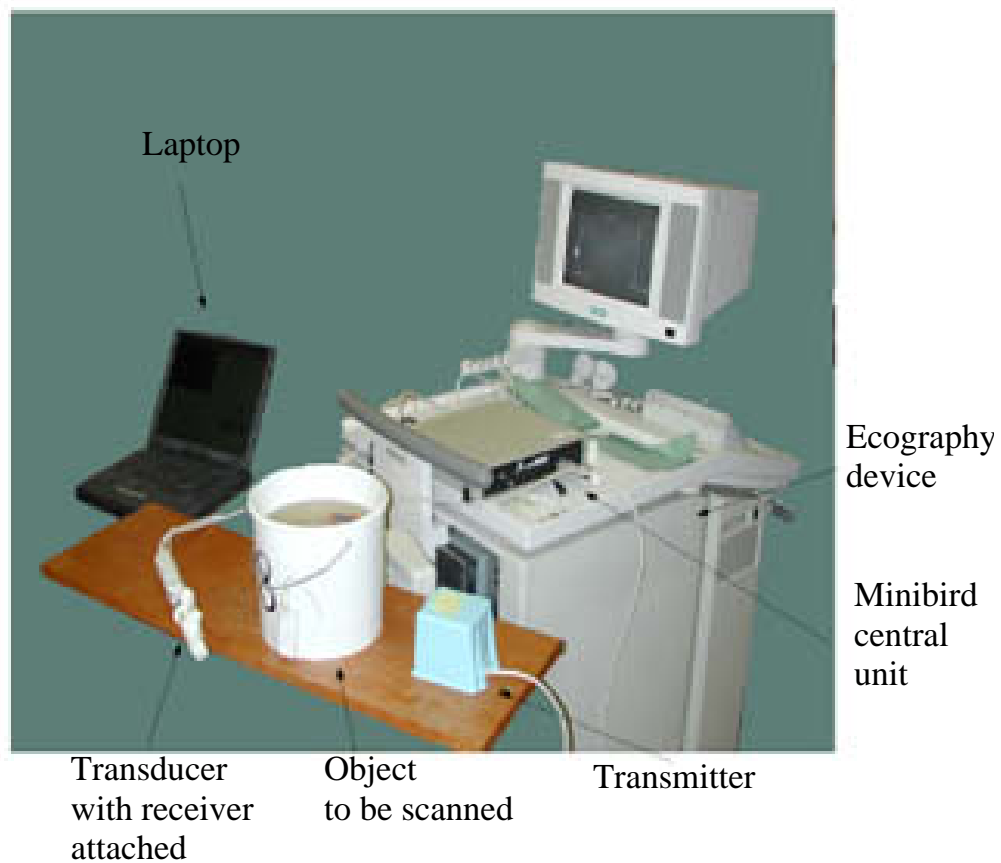


Figure 4.19: Picture of the system to acquire the images; the laptop (left) would read both the video output of ecography device (top right) and the position from the Minibird tracker (blue box). The transducer was attached with the receiver, while the platform supporting the experiment was metal-free to prevent magnetic interferences. The metallic handler of the bucket was actually removed before the scanning commenced.

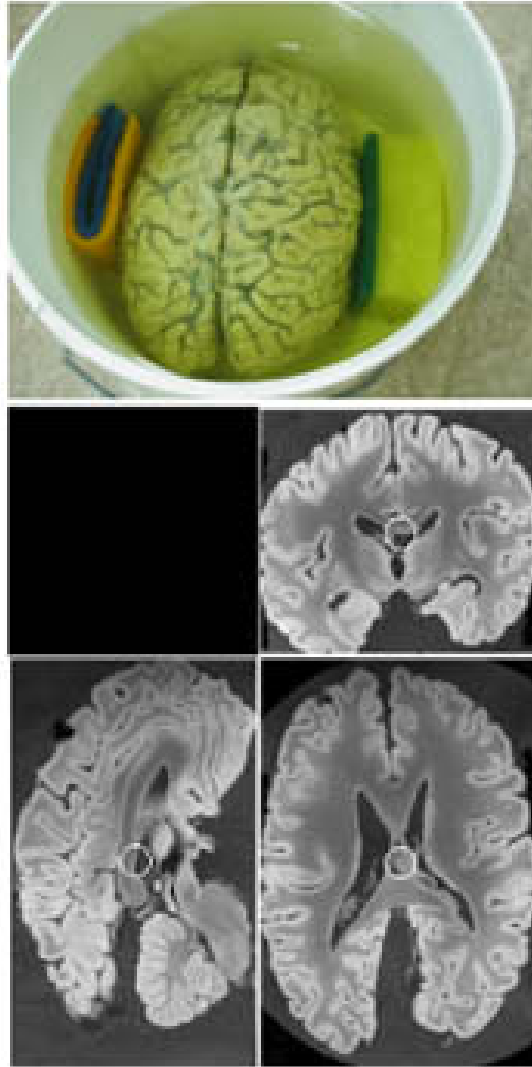


Figure 4.20: Top: Picture of the brain in vitro used in the experiments. Sponges at each side helped to keep the brain in a stable position. Bottom: MR image of this brain.

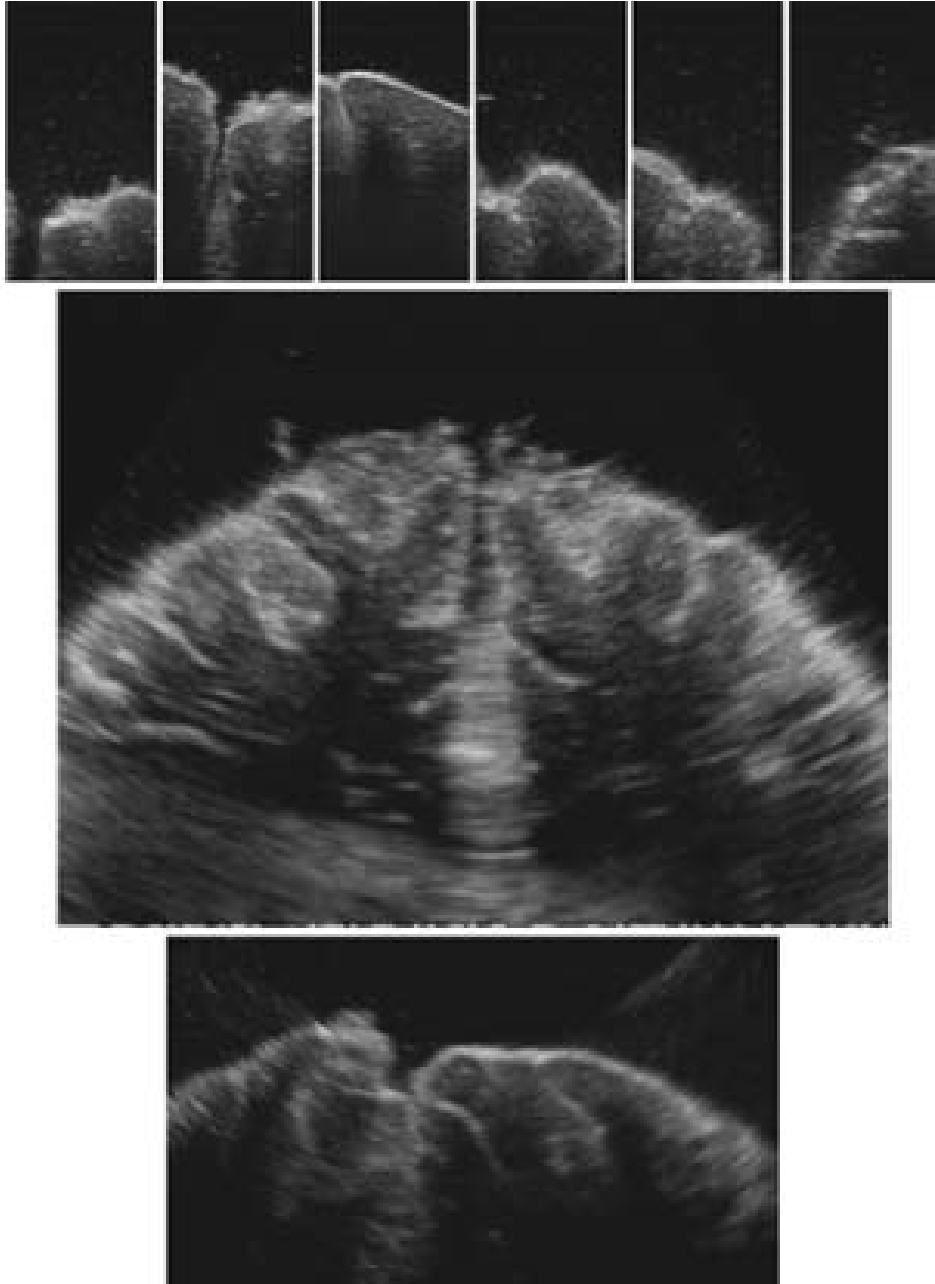


Figure 4.21: Samples of original frames for experiments with 10MHz, 3.5MHz and 6.5MHz (top to bottom). The size of the images drawn is proportional to their field of view.

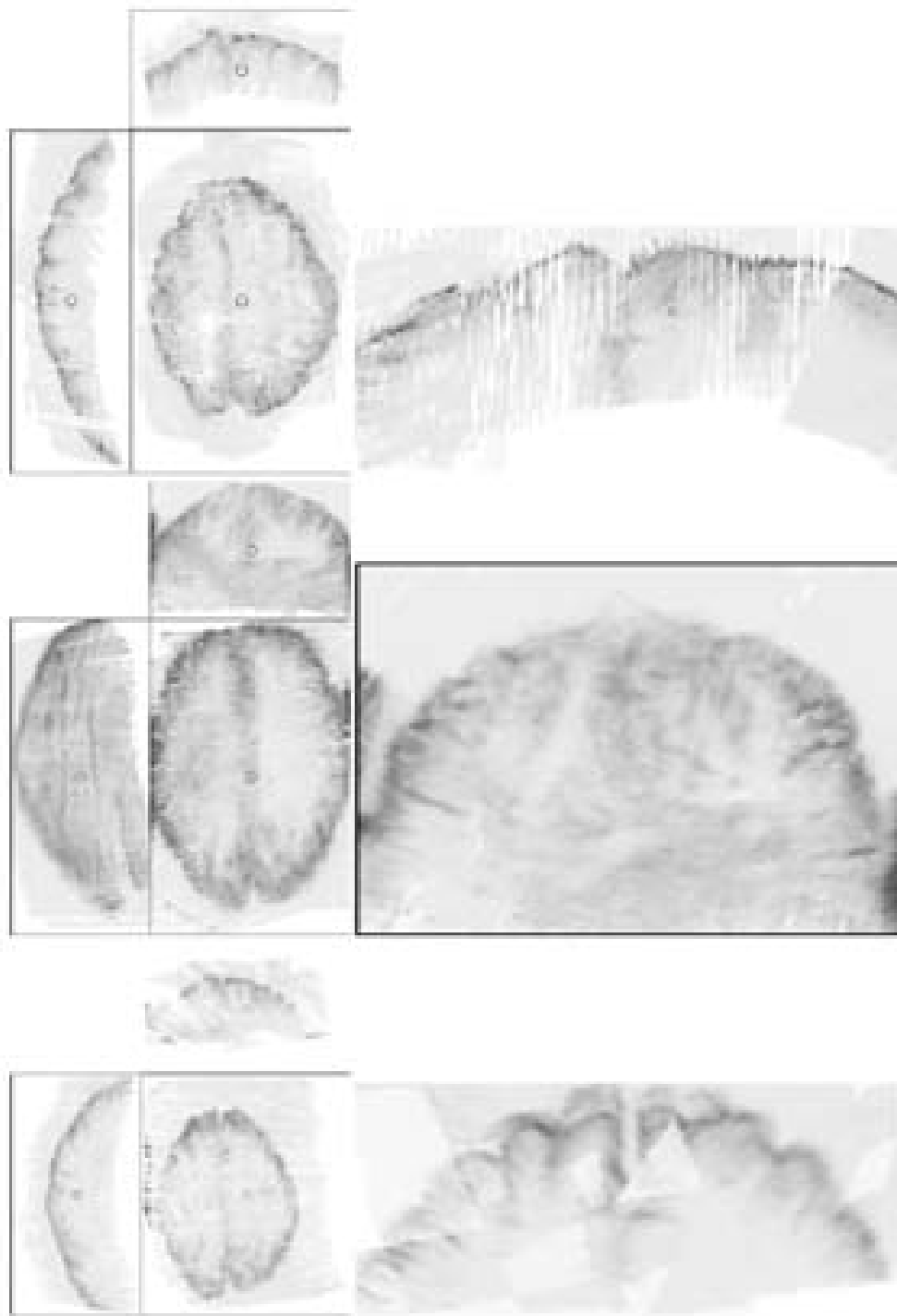


Figure 4.22: Left: orthogonal views of composed 3-D image for the three experiments. Right: coronal magnified view. Note that despite the gaps (top image) and zones darker than others (bottom image) the shape is fairly consistent throughout the image. The graymap has been inverted for better printing.

Experiment	Probe MHz	Pixel size mm	field of view		Frames
			x Pix	y mm	
A	10	0.0938	208	388	1800
B	3.5	0.233	476	364	760
C	6.5	0.163	500	320	530

Figure 4.23: Physical characteristics of the ecographies' video output. The last column is the number of slices required to fill the compounded image.

because of the slow speed of acquisition of our system. To prevent unscanned areas in the compounded cuberille, we acquired several series of frames with different orientation. In general, we proceed as follows:

- place the brain with the sagittal axis about the y axis of the Minibird tracker. The position of the brain in the bucket exposes the upper portion of the brain.
- record one frame with the transducer placed coronal at the middle part of the longitudinal fissure. This information will help to determine the transmitter to cuberille transformation, M_T^C .
- sweep coronally the brain from the back to the front. Cover first the longitudinal fissure, then the other parts. Try to keep the sweeping of the transducer as smooth as possible.
- acquire other swepts in sagittal and other orientations.

After the data had been recorded, we had to compute a suitable M_T^C transformation matrix. This step is important for the visual inspection the compounded image: unusual orientations make difficult to orient spatially. M_T^C was computed after the following the steps:

1. the first recorded frame becomes the xy plane in the compounded image.
2. compute the limits of the scanned area using the previous transformation.
3. given the size of the image to be compounded, compute the scaling in each axis to contain the whole volume to be scanned.

Now, the pixels in the video frame have a known location in the compounded volume. After all the frames have been compounded, the resulting volume would ideally show the regular contains of the scanned area. Two cases occur:

- **Empty voxels** A voxel in the volume has not have been scanned. It is assigned to a constant, usually nil, padding value.
- **Multiply scanned voxels** The value given by each frame will usually be different, and therefore we need a strategy to choose a proper value. The easiest one is simply to store only the last recorded value: the composition algorithm

overwrites the previous value of the pixels. Another approach is to take the mean value of the pixels with the same final location.

We have chosen this last approach for it is more robust to noise and mislocations of the frames. When a frame is out of place, there is a chance that the others are still properly located, and that the mean operation will suppress this error in the final compounded image.

In order to compute the mean value of all intersecting slices, it is not necessary to store the list of values. We simply store for each pixel the accumulated value and the number of hits, and then computing the final image is trivial.

In the next pages we depict the compounded volumes for the three experiments. Of course, the quality of the images is far from resembling other, more accurate modalities such as CT or MR. However, the contours of the brain and also the sulci are clearly distinguishable, specially for distal slices. Proximal slices show features only at the external borders and around the longitudinal fissure, which are the zones the ultrasound signal could penetrate. No other anatomical issues are exposed, because the shape of the container did not permit any scanning of more proximal areas.

Note the gaps in the images, in black, which are areas left non scanned. Also note that some areas are clearer than others. The reason is that, despite the correcting effects of taking the mean value, the image contents degrade as more slices are compounded in, and also with stronger positioning error. These areas appear blurred in the final image. In the next section, we will see more closely this effect and one possible way to suppress it.

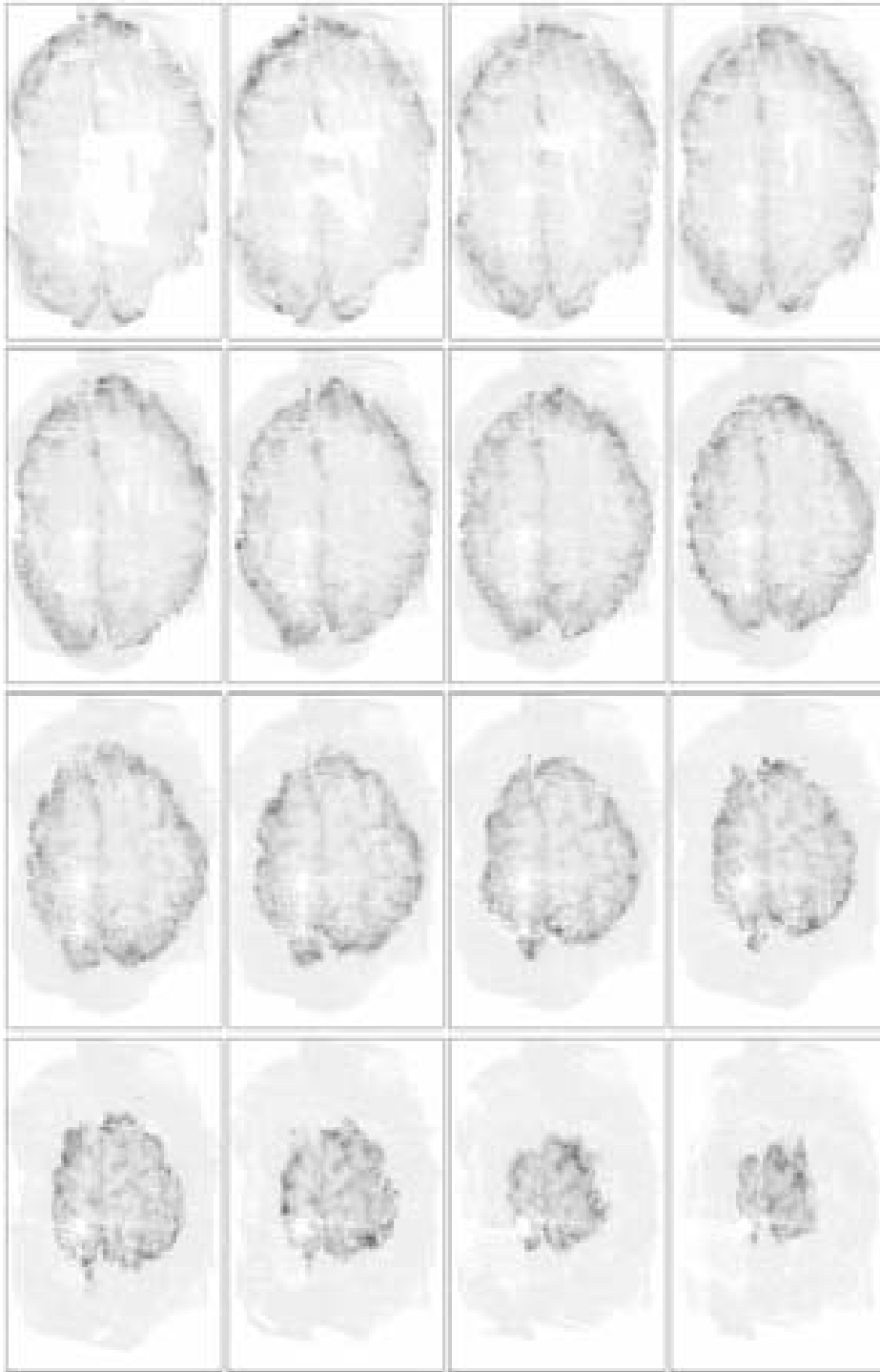


Figure 4.24: Display of 16 slices of the composed cuberille in experiment A (10Mhz probe). (Inverted graymap)

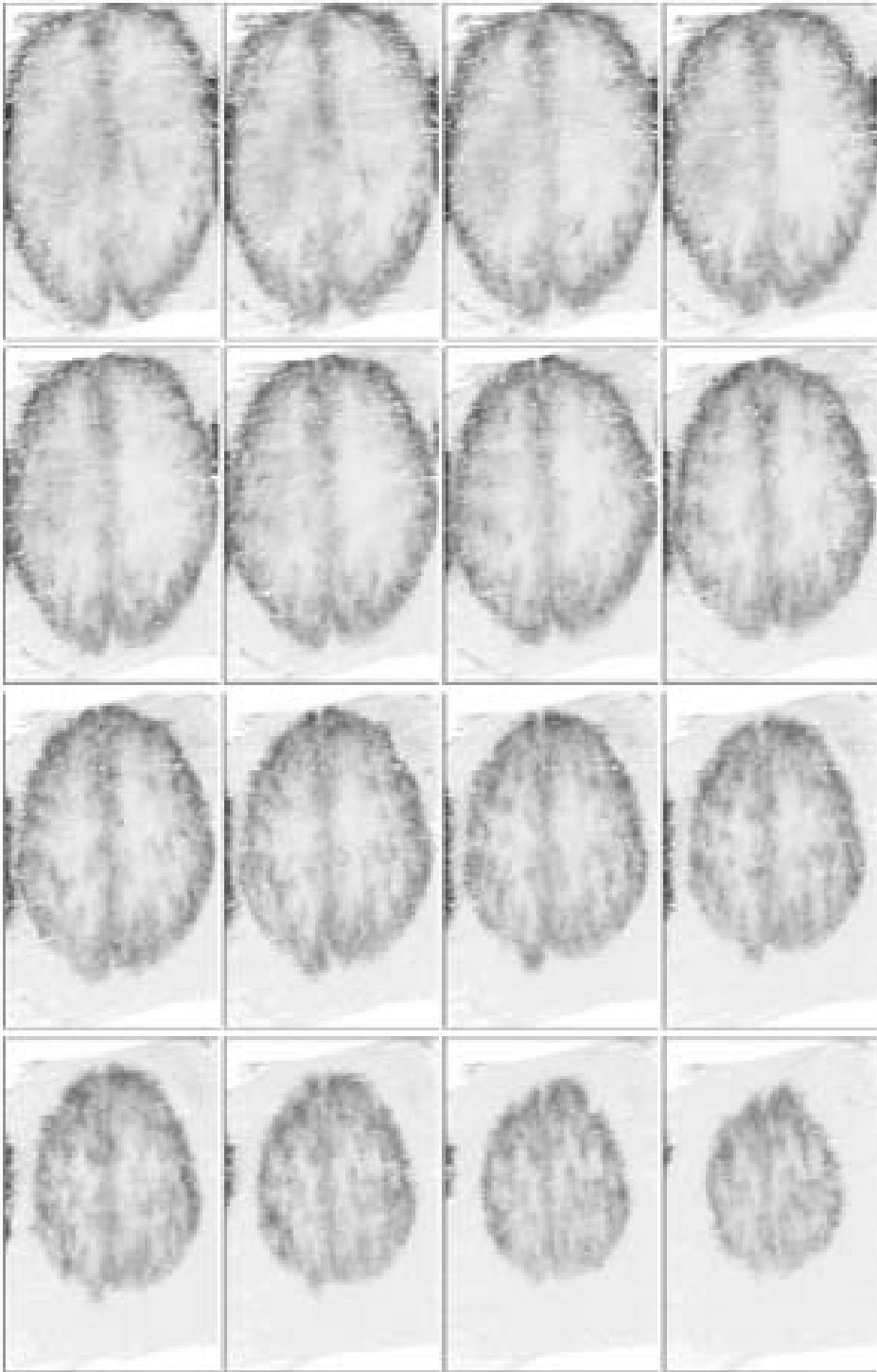


Figure 4.25: Display of 16 slices of the composed cuberille in experiment B (3.5 Mhz probe) (Inverted graymap)

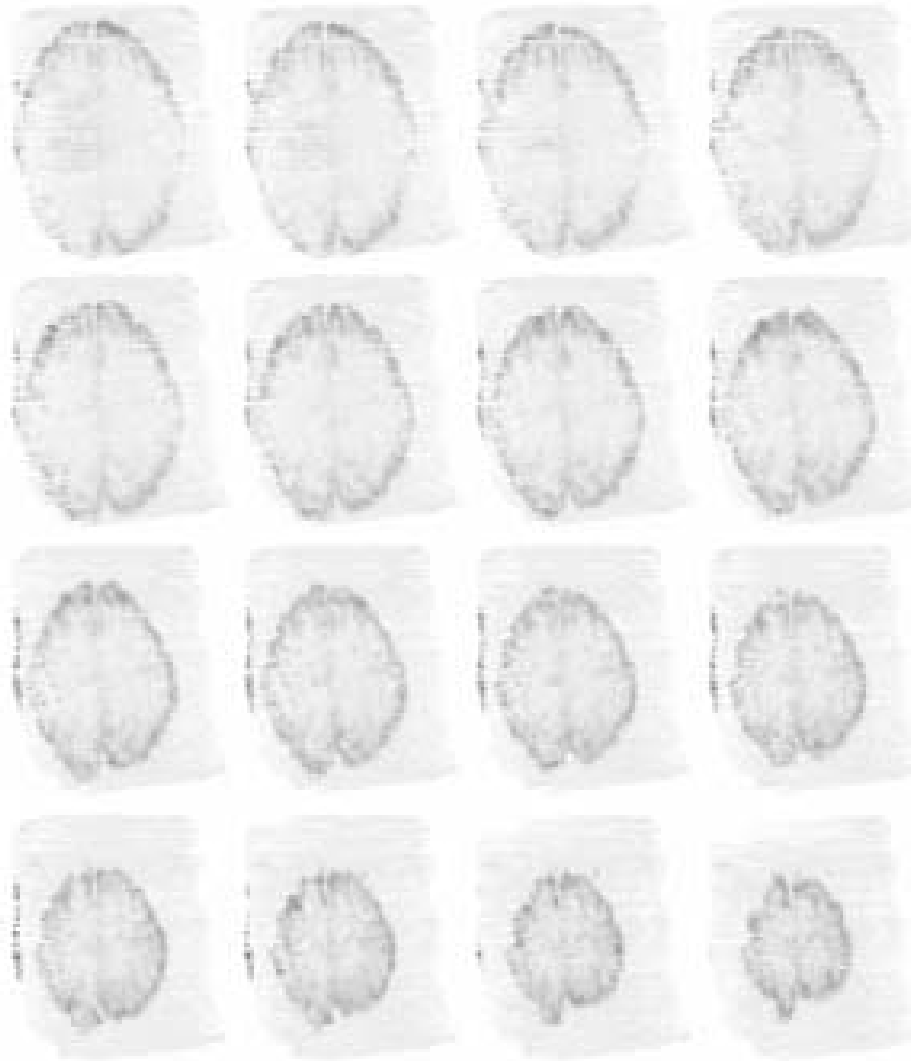


Figure 4.26: Display of 16 slices of the composed cuberille in experiment C (6Mhz probe) (Inverted graymap). The horizontal band appearing on the left zone of slices in the third row corresponds to the sponges used to keep the brain stable.