Automatic Measurement of Brain Height from CT Scans

IRINA EMELYANOVA [1], KRIS PARKER[1], LESLEY CALA [1], ROBERT LINGGARD[1], YIANNI ATTIKIOUZEL[1], KASIA MICHALAK[1], NEIL HICKS[3], PETER ROBBINS[2], FRANK MASTAGLIA [1]
[1]Australian Research Centre for Medical Engineering;
University of Western Australia, 35 Stirling Hwy,Crawley,WA 6009
[2]PathCentre, Hospital Avenue, Nedlands, WA 6009
[3]Sir Charles Gairdner Hospital, Verdun St Nedlands, WA 6009
AUSTRALIA
irina@arcme.uwa.edu.au, kaypy@ee.uwa.edu.au, lesacala@iinet.net.au
http://www.arcme.uwa.edu.au

Abstract: - This paper describes a technique for automatically measuring brain height by processing an X-ray image. The development of this algorithm derives from the need to normalise patient data according to skull size and shape for the purpose of comparing new patient data with that from past cases. The algorithm uses image processing and heuristics to find the location of the external auditory meatus (ear canals), from which the perpendicular distance to the top of the skull may be conveniently measured. The algorithm was applied to a database containing 520 CT brain scans. This paper describes the algorithm and its performance on this data set, and also discusses the statistics of brain height which result from the study.

Key-Words: - CT brain scans, Normalisation, Brain height, External auditory meatus, Skull measurement.

1 Introduction

The motivation for this research work is the desire to provide diagnostic aid to radiologists in interpretation of CT brain scans. It is required that the CT data for a new patient be comparable with that from past cases in order to take advantage of previously successful diagnoses. In such a comparison, it is important to compare like with like, and so the task of normalisation arises. In particular, the skull size and shape, which differ from case to case, need to be normalised, or at least quantified. In addition, it is hoped that this work will establish some statistics on which to base estimates of brain size 'normality'. This paper deals with the problem of measuring brain/skull height. Future papers will discuss the more difficult task of brain/skull shape.

2 Scout Image

In taking a CT Scan of the human brain, the radiographer aligns the patient's head in a standard way. The convention is for the patient to lie supine, head first into the CT scanner. The head is positioned so that the nose points upwards, and the hypothetical line joining the corner of the eye to the meatus of the ear is vertical. This line is called the "orbitomeatal" line [1], and to assist the radiographer in alignment, a red laser light in the form of a vertical line is projected onto the side of the patient's head. With the head in this position, the radiographer then produces a conventional looking X-ray from the lateral position. This is known as the 'scout' image, and it shows the radiologists, who subsequently examine the CT scans, the exact orientation of the patient's head in the scanner. A typical scout image is shown in Fig. 1. The plane formed by the orbitomeatal lines on both sides of the head may be called the skull base-plane. It is used as a reference plane for the axial CT scans which are subsequently made with the patient's head in the same position.

Fig. 1. A typical scout image.

3 Brain Height

Measurement and normalisation of brain dimensions is not a new subject. The well known Talairach system [2] of coordinates uses the anterior and posterior commissure of the corpus callosum as reference points. These ‘landmarks’ are easy to find in MRI images and have been used for normalisation [3] of images in that modality. However, since soft tissue is not discriminated on the scout CT scans, these parts of the brain are not convenient landmarks for use in this study. It was decided to use reference points that rely on bone, which, on CT scans, is always clearly visible. The brain height is thus measured using the bone around the ear canal and the inner bone edge at the highest part of the skull. Since the region between these two bone reference points is the soft tissue of the brain, we feel justified in using the distance between these two points as a surrogate for a measurement of brain height.

Therefore, our definition of brain height is the distance from the midpoint of the head between the ear canals to the inside edge of the bone at the top of the skull, measured perpendicular to the base-plane of the skull. This has several advantages, the main one being that the ear canals and the top of the skull are usually clearly visible on the scout image. In addition, the meatus, which is at one end of the orbitomeatal line, covers the ear canal. Thus, our reference point also relates neatly to the skull base-plane, which is also the reference plane for the axial CT images. In fact, in a scout image taken with the head properly aligned, the brain height is simply the length of the column of pixels between the ear canal and the inside edge of the skull above it. It is clear that the brain soft tissue below the skull base-plane should also contribute to brain height, but we have assumed that this is small and will be in proportion to the measurements we make, and therefore it need not be considered.

4 The Algorithm

The ear canal is the entrance to the middle ear, and thence the inner ear. It passes through the temporal bone almost at right angles to the sagittal plane of the head. Thus, if the head is properly aligned for the scout image, the X-rays pass through one canal and out of the other with minimum attenuation. This means that the ear canals appear as a dark spot on the scout X-ray image set against the white of the temporal bone. It helps that the temporal bone is particularly dense, since this makes it easy to detect as the whitest part of the image. Fig. 2 shows the search area around the ear canal.

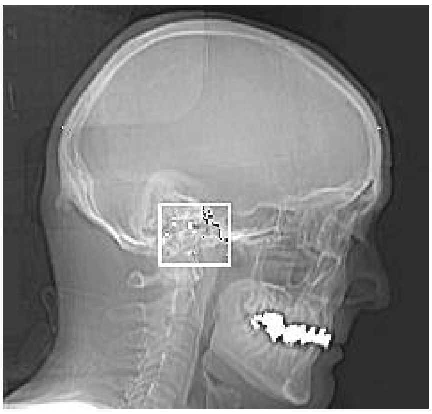


Fig. 2. The search area around the ear canal.

Essentially, the algorithm finds the ear canal by locating the white temporal bone, and searching for a black hole in it. The approximate location of the temporal bone is in the center of the image, so it is not necessary to scan the whole image to find it. As shown in Fig. 2, the search takes place within a square located in the region of the ear canal. Problems arise when the patient is wearing metal earrings. Since metal is even more impervious to X-rays than the temporal bone, it will appear whiter. However, these difficulties are easily overcome.

Having found the ear canal, the next task is to find the inside edge of the skull vertically above the ear canal. This is more difficult because the bones of the side of the skull reduce the contrast between bone and brain. The inner edge of the bone can be hard to find in a thick skull. To overcome this problem, a correlation technique is used, and the comparison is made over the entire column of pixels above the ear canal, extending through the skull. Again, this works well, and the measurement of brain height according to our definition, can be made fairly reliably. Fig. 3 shows several images with which measurements were successful.

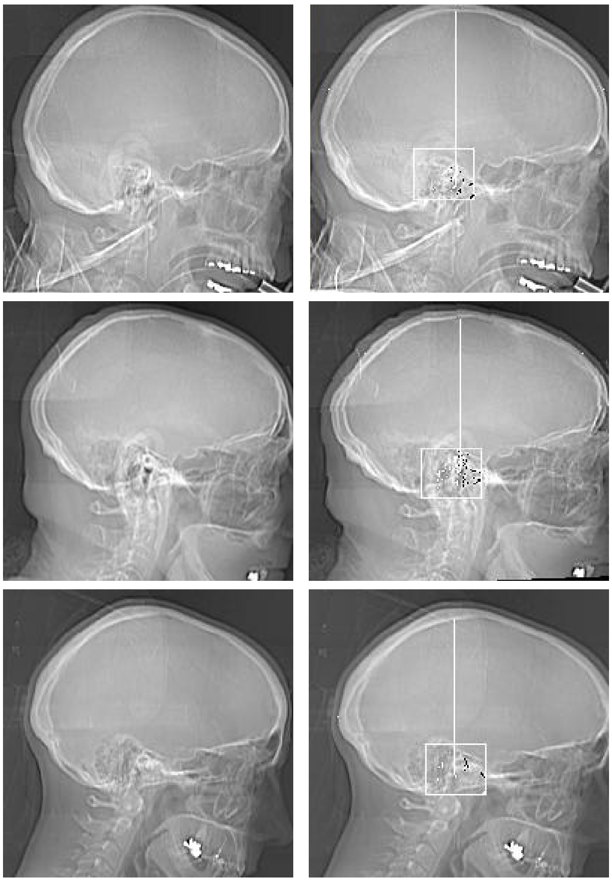
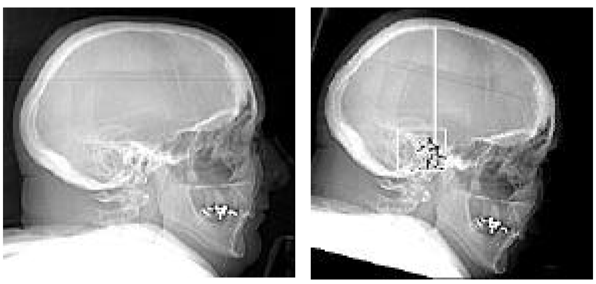


Fig. 3. Examples of successful measurements.

A difficulty occurs when, for one reason or another, the patient's head cannot be tilted forward or back far enough to ensure that the orbitomeatal line is vertical. In such cases, it is usual to tilt the gantry of the CT scanner by an angle that ensures the axial slices are parallel to the skull base-plane. However, the horizontal axis of the scout image is then no longer parallel to the skull base-plane, and hence the top of the skull will not be vertically above the ear canal found in the image.



a. b.

Fig. 4. Brain height measurement if gantry angle is not equal to zero.

The scout image in this case must therefore be rotated by the tilt angle before the measurement algorithm is applied. Fig. 4a shows an example where the head is tilted too far back and so a forward rotation of the image (Fig. 4b) is required before the measurement algorithm is applied.

5 Algorithm Performance

The algorithm was applied to several hundred scout images taken from a database of cases. The performance was good and over 90% of the measurements were found to be accurate when checked by hand. When the algorithm failed, it was usually because the scout image was incomplete or atypical in some way. Fig. 5 shows a case where the top of the skull is outside the image. Fig. 6 shows a case in which the scout image is of the whole body. It is obviously not possible to find the reference points in these cases.

Fig. 5 Example of an incomplete scout image.

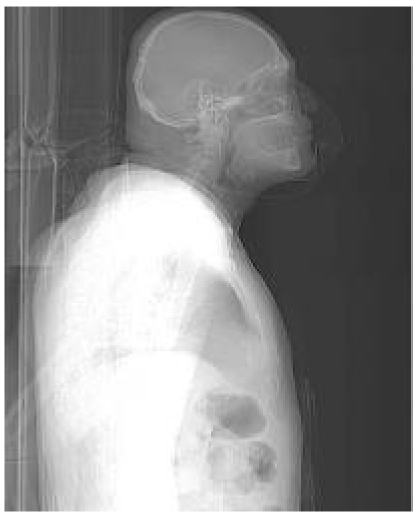


Fig. 6. Example of a 'non-standard' scout image.

6 Results

The results show that the average brain height of all 520 cases examined is 113.1 mm with a standard deviation of 5.01 mm. However, there is a difference in the averages of males and females, with males having an average height of 115 mm, and females 111.5 mm. Of greater interest is that, the standard deviation for males (5.21 mm) is significantly larger than that for females (4.81 mm). Fig. 7 and Fig. 8 show the histograms of the measurements for female and male, respectively. A histogram of height against age showed no significant trend except that some patients under 20 years of age tended to have slightly smaller brains; having perhaps not reached full development.

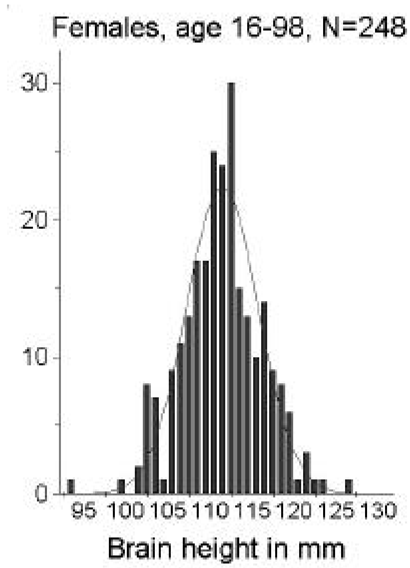


Fig. 7. Histogram of the measurement for female.

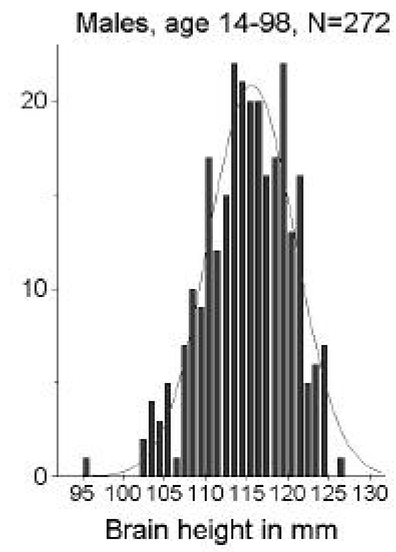


Fig. 8. Histogram of the measurement for male.

7 Conclusions

This study appears to be the first of its kind using CT data taken from large numbers of living patients. The algorithm described is written in Java, and is one of a suite of programs being used for data analysis of CT scans.

The normalisation procedure which follows the measurement of brain height is important in comparing brain scan data from different patients. A measurement of the level above the skull base-plane in mm would be insufficient because brains differ in size, and a level, say, 50 mm above the skull base-plane would not necessarily be at the same anatomical level in two different patients.

Brain size and shape is a more complicated issue and it is hoped to report a system for quantifying and normalising brain shape in a future paper.

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