Computed tomography (CT) and magnetic resonance (MR) imaging to better understand and characterize brain and cranium growth and development.
Fernando VENTRICE

The human brain is a very complex organ that presents several unsolved enigmas, its evolution being perhaps the most intriguing one. This topic is deeply related to the evolution of our own species, and that is the reason why several paleoanthropologists are trying at present to understand the process that gave origin to human brain. Unfortunately, this organ is formed by soft tissue which is not sensitive to the fossilization process. Therefore, we must deal with indirect evidences to infer brain evolution from the fossil record: (1) the well known cranial capacity; the impressiones gyrorum of the different brain gyri and sulci (i.e. lunate sulcus, perisylvian asymmetries); the petalia patterns; and the anatomical compared studies on brains of extant primates (Holloway 1996; Semendeferi et al. 1997; Falk 2006; Schoenemann 2006). Consequently, the fossil record provides only endocranial information. To better understand the clues provided by this information on our brain evolution, it is essential to determine the existing relationship between the brain and the endocranium, and how this relationship develops throughout the maturation process in our species.

Nowadays we have new methodologies to address this question. In this short manuscript two scanning techniques, which may help to better understand and characterize growth and development of human brain and cranium, will be detailed. These two techniques are computed tomography (CT) and magnetic resonance (MR) imaging (Guy, Ffytche 2005). Their physics principles will be formulated, with special attention being paid on the advantages and disadvantages of each technique and their corresponding differences. At the same time, a brief explanation on how their results can be quantified to answer research hypothesis will be given.

The basic physics principle of CT scanning is the reconstruction of an object internal structure from different projections, which are based on X-rays emitted towards the object from different angles. The object presents a variety of absorption rates depending on its constituent tissues. For this reason, when all projections are integrated, CT images are much sharper than X-rays, showing a higher definition not only in bone structures but also in soft tissues (Hsieh 2009).

The MR physics principles are based on the resonance capacity of certain atoms, particularly the protons. When an object is exposed to a strong magnetic field, the small magnetic fields produced by the protons get positioned in a particular direction. After a radio-frequency pulse application, an exciting and relaxing response of the protons is obtained. This response is called resonance, and can be measured and quantified to determine the type of tissue that is being analyzed (Brown, Semelka 2003). In the human body, the molecule responsible for most of this kind of resonance is water (H₂O), since it contains two protons and is present in the tissues in a high percentage.

To highlight the differences between these two scanning techniques is useful to compare the image stacks obtained through each of them. On the one hand, a typical axial head CT image set contains 275 axial images of 512 x 512 pixels, which are obtained in a scanning session lasting 15 seconds and have a voxel resolution equal to 0.5 x 0.5 x 0.5 mm. This volumetric CT stack occupies 144 Megabytes. On the other hand, a sagittal head MR image set would contain 120 sagittal images of 256 x 256 pixels, with a voxel size equal to 1.5 x 1 x 1 mm, in a scanning session that lasts 10 to 15 minutes. This kind of MR stack occupies 16 Megabytes. With this information in mind it is evident that CT images are scanned faster and have a much higher resolution than MR images. So, what is the advantage of MR over CT?

Since these imaging techniques extract different information from
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the same structure, the choice of the most suitable one will depend on the nature of the study that is being performed. For example, in a head CT image, the bones appear white and very clear because they absorb large quantities of X-rays; grease and other soft tissues absorb less quantities of X-rays and appear in a gray scale; and finally, the air absorbs very little radiation, with hollow structures appearing black (Figure 1).

Figure 1: Coronal (upper left), horizontal (upper right) and sagittal (lower left) cranium CT images. Three dimensional (3D) reconstruction of cranium (lower right)

On the other hand, in a head MR image, the bone structures are shown black because of their lack of water, but the soft tissues of the brain can be clearly recognized with high detail: gray matter, white matter and cerebrospinal fluid (Figure 2).

Figure 2: Coronal (upper left), horizontal (upper right) and sagittal (lower left) head MR. 3D reconstruction of cortical brain tissue (lower right) generated using an automatic algorithm for brain extraction.
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Hence, if the objective of the research is to detect a bone fracture or to describe cranium growth, a CT scan should be made. But if the objective is to characterize the brain development, find a certain gyri or discriminate between gray and white matter, a MR scan should be performed. Other important differences arise when it is taken into account the nature of the object to be studied. For example, as it was mentioned above, MR scan can only be done with objects containing water; also, ferromagnetic objects cannot be studied with this technique because of the presence of a strong magnetic field. On the other hand, the CT scan of living humans makes necessary the design of protocols that minimize their exposition time to ionizing radiations. The main differences between these two techniques are presented in Table I.

Table I: Main differences between CT and MR scans.

<table>
<thead>
<tr>
<th></th>
<th>Computed tomography (CT)</th>
<th>Magnetic resonance (MR)</th>
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<tbody>
<tr>
<td>Ionizing radiation</td>
<td>Ionizing</td>
<td>Non ionizing</td>
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<tr>
<td>Contrast</td>
<td>Medium contrast for soft tissue. Bone is perfectly quantified.</td>
<td>High contrast for soft tissue. Unable to quantify bone.</td>
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<tr>
<td>Scan time</td>
<td>Ultra fast scanning times (15 - 30 seconds).</td>
<td>Long scanning times (10 - 20 minutes).</td>
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<tr>
<td>Presence of water required</td>
<td>Any object can be scanned.</td>
<td>Objects must contain water.</td>
</tr>
<tr>
<td>Magnetism</td>
<td>No magnetic field.</td>
<td>Strong magnetic field.</td>
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As it was shown, CT and MR scanning techniques offer valuable and complementary information on the different structures that constitute the studied object. However, as they are solely imaging procedures, they do not provide quantified data; to obtain this, it is necessary to apply complementary techniques. The most simple and straightforward of these is the volume measure of different structures by segmentation procedures: (i) semiautomatic thresholding segmentation to measure endocranial volume from CT head images (Jiang et al. 2007), or (ii) segmentation based on algorithms that can extract, for example, gray matter, white matter, and cerebrospinal fluid from MR brain images (Smith, 2002). Another group of techniques that allows the obtaining of size and shape information from images includes geometric morphometric analysis (Bookstein, 1991; Rohlf, Marcus 1993; Zelditch et al. 2004), and voxel-based morphometric analysis (Ashburner, Friston 2000). The latter enables the estimate of differences between scanned images (e.g.: to compare what brain region grows faster).

In conclusion, the imaging techniques are important tools that can be used to answer a variety of hypothesis and address different aspects of the human brain and its evolution. Particularly, the interest of my research lies in using these two techniques, as well as their complementary ones, to characterize the growth and development of the human brain and endocranium, with special emphasis on the ontogenetic evolution of the relationship between these two structures. This body of knowledge may shed some light on our interpretations of the indirect evidences we have about the human brain evolution.
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Références bibliographiques

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