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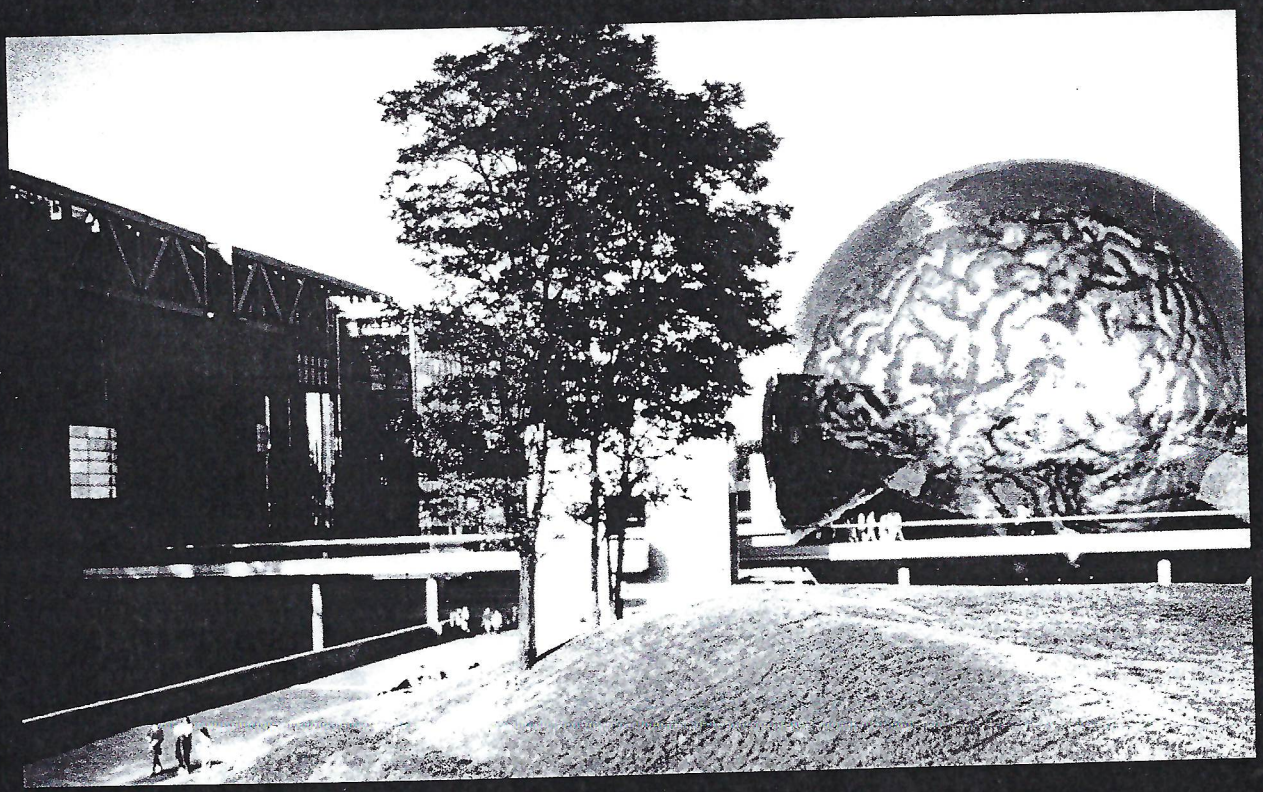

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Diffusion *Tensor* MRI: a New Tool to Elucidate Brain Microstructure and Nerve Fiber Organization

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Introduction.
Recently, we proposed a new MRI modality--diffusion tensor imaging (DTI) (1)--that exploits diffusion anisotropy in tissues to elucidate microstructure and microdynamics. In DTI, we estimate an *effective* diffusion tensor, $\underline{D}$, in each voxel from DWIs and derive from $\underline{D}$, quantities such as the direction of nerve fiber-tracts, and MRI parameters that are independent of fiber orientation (1). Here we present two such parameters, one to measure *diffusion anisotropy* and the other to measure *nerve fiber-tract organization*.

Theory.
The *anisotropic* part of $\underline{D}$ is a new tensor quantity, the *diffusion deviation tensor*, $\underline{D}$,

$$\underline{D} = \underline{D} - \langle D \rangle \underline{I} \quad \text{with} \quad \langle D \rangle = \mathrm{Tr}(\underline{D}) / 3 = (D_{xx} + D_{yy} + D_{zz}) / 3 \qquad (1)$$

where $\underline{I}$ is the identity tensor (δ_{ij}), and $\langle D \rangle$ is the (scalar) invariant mean diffusivity. The matrix product of diffusion deviation tensors, $\underline{D} : \underline{D}$, is a new scalar invariant quantity that we use as the basis of a dimensionless measure of diffusion anisotropy, DA, (see Eq. *(2)*). Moreover, the matrix product of diffusion deviation tensors estimated in *different* voxels at positions $\mathbf{r}$ and $\mathbf{r}'$, $\underline{D}(\mathbf{r}):\underline{D}(\mathbf{r}')$, is the basis of a new dimensionless, scalar invariant measure of *fiber organization*, OI, (see Eq. *(3)*) in which this matrix product is weighted by a convolution kernel, $K(\mathbf{r}-\mathbf{r}')$, and integrated over the entire image volume, V. Both DA and OI are defined below:

$$DA = \frac{\sqrt{\underline{D} : \underline{D}}}{\langle D \rangle} = \frac{\sqrt{\sum_{i=1}^{3}\sum_{j=1}^{3}\left(D_{ij} - \langle D \rangle \delta_{ij} \right)^2}}{\langle D \rangle} \quad (2); \qquad OI(\mathbf{r}) = \frac{1}{V} \frac{\int_V \underline{D}(\mathbf{r}) : \underline{D}(\mathbf{r}')\, K(\mathbf{r}-\mathbf{r}')\, d\mathbf{r}'^3}{\langle D(\mathbf{r}) \rangle^2} \quad (3)$$

Materials and Methods.
We acquired DWIs of live monkey and cat brains using a 2-T CSI-Omega imager with a quadrature head coil, and of human brains using a 4-T GE-Omega whole body imager. We employed fast DWI sequences using multislice 2D-FT spin-echo and STEAM DW interleaved EPI. In humans, we estimated $\underline{D}$ optimally in each voxel (1-3) from twenty high-resolution (128x128) multislice DWIs (acquired in under one hour) in which we applied diffusion gradients in at least six different oblique directions(3).

Results.
Diffusion anisotropy index images highlight anisotropic brain white matter while isotropic grey matter and ventricles appear dark. *Fiber organization index* images only highlight highly ordered nerve fiber-tracts (in the optic nerve and corpus callosum).

Conclusion.
DTI combined with EPI addresses the needs a) to characterize cell, tissue, and organ architecture during brain maturation, aging, and degeneration, as well as b) to relate brain architecture to physiological function in health and disease (e.g., myelin disorders and neoplasms). DTI via EPI is also clinically feasible.

References.
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