In vivo placenta diagnosis by water diffusion Magnetic Resonance Imaging

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We aimed to find biomarker to characterized and differentiate healthy and pathological placentas using Nuclear Magnetic Resonance Diffusion weight imaging (DWI) technique. The knowledge of diffusion behavior in human gives microstructural and physiological information of tissues without requiring exogenous contrast agents. In fact, the diffusion of water molecules in biological tissues is hindered by the presence of membranes and vessels. Fetal and maternal placenta's tissues are characterized by a different amount of biological water diffusion (in parenchyma) and perfusion (in the villi and between fetal-mother placenta interface). Diffusion and perfusion can be quantified using Intravoxel-incoherent-motion (IVIM) model of MRI signal acquired using a specific acquisition sequence that provides DWI.
We developed and tested a new biophysical model based on diffusion MRI (DMRI) imaging to quantify perfusion and diffusion in human placenta. Specifically, the multi-compartment model is characterized by two perfusion compartments and one diffusion compartment. The signal decay is due by the following expression:
$S=S0\cdot(f1\cdot\exp(-b\cdot(D1^*+D2^*+D))+f2\cdot\exp(-b\cdot(D2^*+D))+(1-f1-f2)\cdot\exp(-bD))$
where D is the diffusion coefficient, f1 is the perfusion fraction of the fastest fetal compartment (perfusion in villi), f2 is the perfusion fraction of the other fast compartment (trophoblastic compartment), D1* and D2* are the perfusion coefficients characterizing the fast compartments.
Data from 51 pregnant women (Gestational weeks mean+/-std = 26.87+/-5.26w) were acquired at 1.5T scanner (Siemens Avanto, Erlangen, Germany). The acquisition protocol included a Diffusion-weighted Spin-Echo Echo-Planar Imaging with repetition time/echo time, TR/TE=3900ms/74.8ms; bandwidth=1184Hz/px; matrix size=192x192, FOV 220x220, number of slices=from 18 to 30. The in-plane resolution was 2.0x2.0mm2 and the slice thickness 5mm. The diffusion encoding gradients were applied along 3 no-coplanar directions using seven different b-values (0,10, 30, 50,75,100,200,400,700,1000 s/mm2) and averaged over the three directions. The number of averaged signal (NS) for each b value was NS=4. A Matlab (MathWorks, 2016b) home-made script was used to fit the multi-compartment model to the data. A machine learning algorithm based on bugged tree was used in order to obtain the parametric maps.
Six ROIs were manually placed on each placenta on different areas of both Fetal and Maternal side.
The diffusion coefficient was calculated through the fitting of the last three b-values with a monoexponential model. The obtained value was fixed in the IVIM model. Finally it was fitted the multi-compartment model where the fixed parameters were the diffusion coefficient (D) and the perfusion fraction (f) obtained by the IVIM model, where f=f1+f2 in our new model. This procedure should stabilize the resulting fitting.
The dataset is divided into two groups: 43 healthy subjects and 9 pathologic subjects classified as fetal grow restriction (FGR) by a ultrasound investigation. F2 found significant difference between fetal and maternal side which is connected to the role of trophoblastic cells involved into the exchange of nutriments between fetal and maternal blood. This perfusion fraction also discriminates healthy and FGR placentae. D and f1 didn't discriminate between healthy and FGR group.
In conclusion, diffusion and perfusion model applied to diffusion MRI in placentae is a powerful non invasive, radiation-free tool for prenatal diagnosis. The perfusion fraction f2 that quantifies perfusion through trophoblastic cells involved into the exchange of nutriments between fetal and maternal blood could be a biomarker to discriminate normal and pathological placentae.

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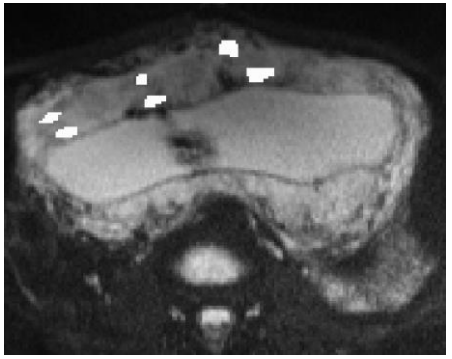

Figure 1. Healthy placenta of 22 w GA with umbilical, periferical and central ROIs (white areas) taken in fetal and maternal side.

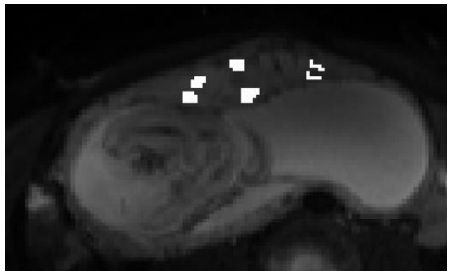

Figure 2. IUGR placenta of 19 w GA with umbilical, periferical and central ROIs taken in fetal and maternal side.

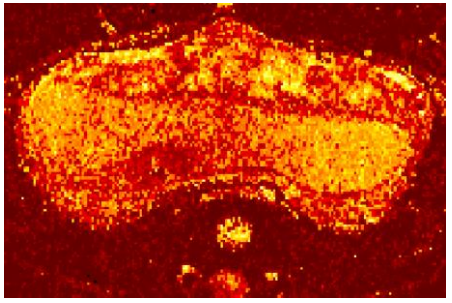

Figure 3. Diffusion map of a healthy placenta obtained with a machine learning algorithm. The map shows the mean diffusivity in placenta parenchima

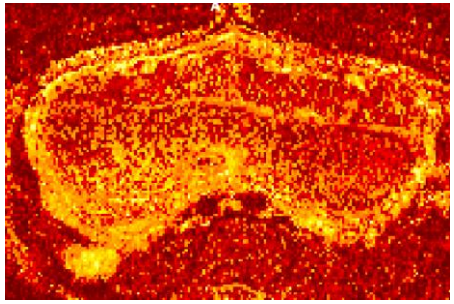

Figure 4. f2 map of a healthy placenta obtained with a machine learning algorithm. F2, represents the perfusion fraction through trophoblastic cells involved into the exchange of nutriments between fetal and maternal blood