BOLD fMRI and fcMRI in the Pediatric Brachial Plexus Injury Population: Evaluating Cortical Plasticity

Rupeng Li[1], Jacques A Machol IV[2], Nicholas A Flugstad[2], Ji-Geng Yan[2], James S Hyde[1], and Hani S Matloub[2]
[1]Biophysics, Medical College of Wisconsin, Milwaukee, WI, United States, [2]Plastic Surgery, Medical College of Wisconsin, Milwaukee, WI, United States

Target Audience: Researchers and Physicians working on pediatric fMRI/fcMRI study of sensorimotor system.

Purpose: Setup study method that can be used for both pediatric (infants) and adult patients to study sensorimotor system with fMRI/fcMRI with pinpoint accuracy.

Methods: 3.0 Tesla GE Signa LX 750 short bore scanner with 32 channel receiver coil array was used to collect fMRI signal. In order to get pinpoint stimulation of peripheral sensory, which is also required to be touchless due to Children IRB regulation, we built up an air-puff stimulator delivering CO_2 to the skin surface to perform stimulation task (Figure 1). As an example, a 10 month old female patient with left side brachial plexus injury (BPI) was scanned. The patient was swaddled and fell asleep after regular feeding; no pharmacologic interventions were undertaken. Due to the touchless feature of our setup, the infant remained sleep during the entire scan with only minimum head motion. AFNI and MATLAB were used to process the fMRI/fcMRI data. An initial scan provided T1 weighted spoiled GRASS (SPGR) (TI/TE/FA = 450 ms/3.2 ms/12°, FOV = 24 cm, number of slices = 124, slice thickness = 1.2 mm). This was followed rs-fcMRI scans to acquire gradient echo planar imaging with T2* image contrast. EPI was then undertaken using parameters TR/TE/FA = 2000 ms/30 ms/77°, with axial slice sizes of FOV = 25.6 cm, matrix = 128 x 128, slice thickness = 1 mm. Voxel size was 1 mm3. Somatosensory stimulation was provided as described above during each EPI phase. The EPI scan was completed in duplicate per side. Motion was addressed with post-scan correction algorithms during data analysis. For comparison and further test, a healthy adult was also scanned with the same setup.

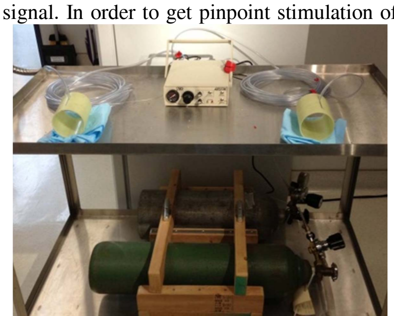

Figure 1. Air-puff stimulator using CO_2 to stimulate peripheral sensory with high accuracy.

Results: For the infant with BPI, electromyography (EMG) was also indicative of a neurogenic lesion affecting the left C5 and C6 nerve roots. Surgical exploration and intra-operative EMG prior to nerve reconstruction confirmed a large neuroma at the level of the C5 and C6 roots. The axillary nerve was also with scarring at the level near the posterior division (Figure 2). Figure 3 demonstrates BOLD fMRI response of the BPI patient (both sides) and the healthy adult (one side) using high accuracy air-puffs as stimulation. No sensory response can be detected when the deltoid region of the injury side was stimulated (Fig.3A). A distinct fMRI sensory response can be found in the non-injury side of the birth palsy patient (Fig. 3B) and the healthy adult (Fig. 3C). It is noted that for this air puff stimulation on the Deltoid region, two locations in the post central gyrus area are activated in both the healthy adult and the healthy side of the BPI pediatric patient. Since the nerve injury was limited to C5-6 nerve root in brachial plexus nerve roots, the overall motor function and sensation of the involved limb was diminished. In order to see the overall sensory network function, fcMRI was performed using the high accuracy seeds acquired from the BOLD fMRI scans. As the result, diminished somatosensory network contralateral to the nerve injury was demonstrated while the other hemisphere remained normal (Fig. 4A). The same network remains symmetrical in healthy adult (Fig. 4B). Because of the high accuracy BOLD fMRI scan, the two site activation pattern was repeated in the fcMRI results.

Posterior Deltoid	Middle Deltoid	Anterior Deltoid	Supraspin.	External Rotators	Biceps & Brachialis	Brachiorad.
0	2	2	1	0	3	0
Supinator	Latissimus dorsi	Pectoralis major (clavicular)	Pectoralis major (sternal)	Pronator teres	Serratus anterior	ECRL
0	1	2	3	3	3	3
EDC	Triceps	APL	EPL	ECU	FCU	FCR
3	3	2	0	3	3	3
FPL	FDS	FDP	Interossei	APB	OPB	ADD
3	3	3	3	3	3	3

Figure 2. Intro-op picture and pre-op EMG validating the C5-C6 nerve root injury in the 10 month old patient.

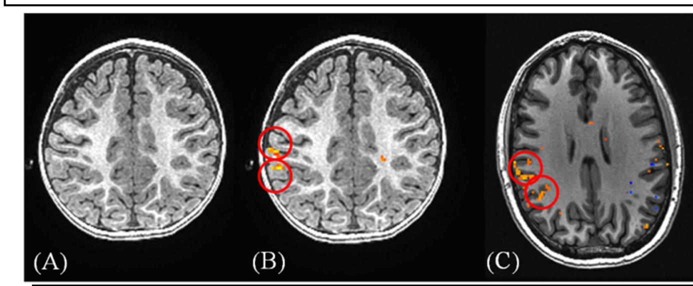

Figure 3. BOLD fMRI of air-puff stimulation in deltoid area. (A) BPI side of patient (B) healthy side of patient (C) healthy adult

Discussion: Studying peripheral sensory in pediatric population is always challenging. Due to the patients' age, they cannot cooperate to perform any task or communicate with others. Also because of this, the Children IRB always has a very strict regulation on devices that directly contact these patients. The new setup we developed in this study can be applied to almost all the fMRI/fcMRI studies dealing with sensory function in children and adults and deliver high accuracy mild sensory stimulations. The subject could be awake or asleep and the result remains consistent. Ultimately, this model will be utilized to prospectively investigate cortical sensory plasticity after nerve transfer for brachial plexopathy treatment. Dramatic neuronal plasticity was revealed in the pediatric BPI patient. This plasticity happens both intra and inter-hemispherically suggesting the profound CNS remodeling caused by peripheral nerve injury. Currently, nerve transfer surgery is being performed worldwide to restore the nerve function. However, around 40% of the clinical outcome is not satisfied despite the nerve repair procedure is done successfully. We believe the CNS factor play a very important role in this recovery process that by repair the peripheral nerve injury, the entire sensory/motor network is remodeled. The difference in this modeling process might be the answer of the diverse clinical outcomes and it is also the goal of the future post-surgery rehabilitation.

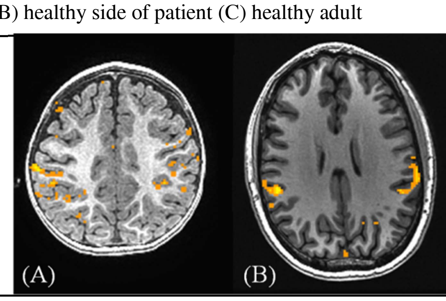

Figure 4. fcMRI of sensory network with seeds from high accuracy BOLD fMRI. (A) BPI patient (B) healthy adult

Conclusion: With the development of air-puff stimulator, fMRI and fcMRI of peripheral sensory can be studied in both pediatric population and adults. Following BPI, dramatic CNS plasticity happens that results in both local and large scale changes in the sensory network. This method serves as a tool to further improve the surgical outcome and functional recovery.