Introduction

- Brachial plexus birth palsy (BPBP) occurs in approximately 1/1000 live births\textsuperscript{1,2}

- The most common of these palsies involve the C5-C6 roots of the brachial plexus\textsuperscript{3}

- A number of surgical procedures for reconstruction have been introduced\textsuperscript{4}

- Likewise, blood oxygen level dependent (BOLD) Functional MRI (fMRI) has provided a reliable method for indirectly studying task-induced cerebral neuronal activity\textsuperscript{5-6}

- This imaging exploits changes in deoxygenated hemoglobin (dHb) concentrations, which, in turn, act as an endogenous paramagnetic contrast agent

Figure 1. Signal in fMRI
Introduction

• Cortical metabolism is almost exclusively aerobic

• Thus, the local dHb to Hb ratio measured by fMRI can be interpreted as an indirect measurement of neuronal activity

• Likewise, Functional Connectivity MRI (fcMRI) uses spontaneous low frequency BOLD fluctuations to demonstrate cortical connectivity\(^7\text{-}^9\)

• Our laboratory has extensive experience utilizing fMRI to reveal cortical plasticity following peripheral nerve injury and repair\(^{10\text{-}15}\)

• No human studies assessing cortical changes after BPBP exist

Figure 1. 9.4T fMRI during C7 (top) and median nerve stimulation (bottom)\(^{10}\)

Introduction

- We employ 3T BOLD fMRI and fcMRI in a pre-operative pediatric BPBP patient and a healthy adult.

- Assess post-injury cortical changes using Air-Puffer somatosensory stimulation\(^{16}\)

- Post central gyrus chosen as the region of principal evaluation (primary sensory cortex)\(^{17}\)

- fMRI and fcMRI of the BPBP patient’s injury side sensory cortex is contrasted to:
  - Non-injury side (internal control)
  - Healthy adult cortex

- We hypothesize that there will be significant differences in BOLD signal noted for both comparisons.
Methods

- 10 mo Female
- Left C5-C6 BPBP
- 0/5 Ext. Rotators
- 0/5 Post. Deltoid
- No withdrawal with pinch of lateral deltoid
- Modified Mallet Classification
  - Global Abduction III
  - External Rotation III
  - Hand to Neck I
  - Hand to Spine II
  - Hand to Mouth I

Table 1. Upper Extremity Functional Exam using the Medical Research Council (MRC) Scale for Muscle Strength.
0: no function – 5: contracts against full resistance. Testing was performed within the best ability given the patient’s age.
Methods

• Modified Mallet Classification
  – Global Abduction III
  – External Rotation III
  – Hand to Neck I
  – Hand to Spine II
  – Hand to Mouth I

• The C5-C6 pathology was verified with pre-operative EMG

• Post-scan surgical exploration and intra-operative EMG confirmed neuroma at C5-C6 (during nerve transfer)

Figure 3. Intra-operative image of nerve transfer after identification of C5-C6 neuroma. Thoracodorsal n. to Axillary n. (side to side) with neurolysis was completed.
Methods

• Children’s Hospital of Wisconsin IRB and MCW MRI Safety approval obtained

• GE 3.0T short-bore utilized for MRI scans

• A timed air-puff stimulator using CO2 gas was connected to two tubes to intra-MRI arm cradles

• One tube was designated the RUE and the other was directed to the LUE

• The lateral deltoid was selected for stimulation

• C5-C6 dermatome

Figure 4. Air-Puffer Mechanism. AIRSTIM™ controlled L and R UE tubes to bilateral, intra-scanner, custom machined, G-10 fiberglass arm cradles. Each arm cradle was padded prior to use. This design prevented arm flexion and allow specific dermatome sensory targeting (C5-C6). CO2 gas was regulated to 60psi.
Methods

- **Pre-op** 3T BOLD fMRI imaging was performed (BPBP patient).

- Air-puff stimulus to the left (injury) and the right (non-injury) sides during the EPI phase - completed in duplicate during separate imaging runs.

- fMRI of the pediatric **injury side cortex** was compared to the **non-injury side cortex**.

- The injury patient’s post-central gyrus cortical function was then compared to a **healthy 31 year old adult** using identical somatosensory stimulus BOLD fMRI protocols.

- fcMRI was then performed to evaluate sensory connectivity differences between the healthy adult and the BPBP patient.

**Methods**

- Echo Planar Image (EPI) data from each scan was averaged and masked using Analysis of Functional Neuro Images (AFNI) software\(^9\).

- \(P\)-value threshold of \(\leq 0.005\) was set to determine significant Voxel activation (BOLD Signal) - **Voxel** – Represents 2.5 mm\(^3\) (Similar to a 3D pixel).

*Figure 5.* Air-Puffer Stimulus Timing during the EPI phase of the BOLD fMRI. The puffer remained off for 40 seconds, then on for 20 seconds. This was repeated five times followed by a rest period of 40 seconds. 60psi of CO\(_2\) was used as stimulus in the C5-C6 dermatome. (s = seconds)
• Results
  
  • Right deltoid (non-injury) somatosensory stimulus
    - BOLD Signal noted in the patient’s left post-central gyrus

  
  Figure 1. 10 Month Female BPBP. Coronal (above) and Axial (below) fMRI during healthy right deltoid air-puff stimulation. BOLD signal noted in left post central gyrus. (crosshairs and arrow denote signal)
Results

- **Left deltoid (injury) somatosensory stimulus**
- Lack of BOLD signal in the post central gyrus in the right cortex
- Intra-cortical changes noted as compared to the non-injury cortex

**Figure 2.** 10 Month Female BPBP. Coronal (above) and Axial (below) fMRI during injury left deltoid air-puff stimulation. No BOLD signal noted in right post central gyrus. (*crosshairs and arrow denote signal*)
• Intra-cortical variance was also illustrated when compared to a healthy adult subject

• The BOLD signals during the healthy limb studies appeared to closely match (top and bottom left)

• Whereas, the somatosensory cortical representation of the pediatric injury side did not demonstrate BOLD signal at this significance, P < 0.005 (top and bottom right)

• Figure 3. BOLD fMRI of Axial Healthy Adult Left Deltoid stimulation vs. Healthy Pediatric side vs. Injury Pediatric Side
fcMRI demonstrated connectivity difference between the healthy subject and the BPBP patient.

**Healthy Adult:** symmetrical, bilateral somatosensory networks are demonstrated using fcMRI techniques (Top)

**BPBP Patient:** a similar sensory network is shown when the fcMRI seed was chosen from the healthy cortical side (L cortex for R deltoid)

However, the injury side cortical network has less organization (Arrow, R cortex for L deltoid)

**Figure 3.** fcMRI of Axial Healthy Adult (above) with symmetric connectivity. Pediatric Left BPBP (below) with less network connectivity in the right cortex.
Conclusions

• This novel application of 3T BOLD fMRI and fcMRI has demonstrated intra-cortical somatosensory functional and connectivity differences in a high BPBP patient.

• The model proposed is applicable to demonstrate cortical sensory changes in the pre and post-operative patient with BP injuries.
Conclusions

- Limitations: small patient sample size, comparison to adult, and no motor or post-operative imaging

- Represents the early phase of prospective pre and post-operative fMRI studies

- **Goals:** Evaluate cortical plasticity after nerve transfer surgery for BP injury in the pediatric and adult populations

- Track treatment progress or assess candidacy for nerve transfer or other reconstructive procedures
References