Shape Analysis of the Caudate Nucleus of Newborns

Haissam Haidar[1,2], Sylvain Bouix[2,3], André J. du Plessis[1], and Janet S. Soul[1]
[1] Department of Neurology, Children's Hospital and Harvard Medical School, Boston, MA.
[2] Surgical Planning Laboratory, Department of Radiology, Brigham and Women's Hospital and Harvard Medical School, Boston, MA.
[3] Clinical Neuroscience Division, Laboratory of Neuroscience, Boston VA Health Care System, Brockton Division, Department of Psychiatry, Harvard Medical School, Boston, MA.
{haissam, sylvain}@bwh.harvard.edu,
janet.soul@childrens.harvard.edu

Abstract. We present an analysis of shape of the caudate nucleus in prematurely born infants. In particular, we compare shape of caudate between healthy preterm infants and those with white matter injury. We applied a novel method based on the solution of Poisson's equation to perform this analysis. Our preliminary results on a complex shape such as the newborn caudate show the advantage of our method for detecting subtle differences in shape.

1 Introduction

A full term baby is born at around 40 weeks of gestation. In the United States, 12% of newborns are born prematurely each year. The most rapidly growing segment of the preterm population is the 47% of premature infants born between two and three months too early, and weighing less than 1500 grams. Over 50% of them manifest significant learning disabilities at school age. The motor control and learning difficulties of these premature infants are likely related to white matter injury (WMI). The WMI that occurs in many very low birth weight infants is thought to result from increased vulnerability of the oligodendrocyte and periventricular white matter to hypoxia-ischemia and infection [1]. Recent advances in magnetic resonance imaging (MRI) allow better detection of this sometimes subtle WMI. However, MRI studies have demonstrated that children born prematurely have evidence of cortical and subcortical gray matter abnormalites as well [2-4] One study of adolescents born prematurely showed that lower IQ scores correlated with smaller right caudate and left hippocampal nuclei [4]. Subcortical gray matter structures play an essential role in cognitive functions. Quantification of their changes during the *neonatal* period will improve our understanding of the developmental impact of early acquired brain injury. In this work, we applied our novel method for shape analysis of anatomical structures [2] to compare the shape of caudate nuclei of premature infants with and without WMI. Our preliminary results demonstrate the ability of our method to find differences in shape between groups in a small structures such as the caudate nucleus in the newborn infant.

2 Methods

Thirteen premature infants with asymmetric white matter injury (WMI) and eight premature infants without evidence of WMI (NI) underwent MRI scans at term equivalent age (39-42 weeks postconceptional age, PCA). All infants were born at 24-29 weeks gestational age, but infants with WMI had germinal matrix-intraventricular hemorrhage and a unilateral periventricular hemorrhagic infarction (WMI). MRI data were acquired in the coronal plane with a 1.5T GE scanner, using a three-dimensional SPoiled Gradient Recalled (3D SPGR) sequence yielding a voxel size of 0.703125x0.703125x1.5mm. An expert user (JSS) segmented the head of the caudate nuclei manually using the 3D SPGR images. Details of the technique of manual segmentation have been described previously [3]. We applied our method of shape analysis of anatomical structures to this set of data. Our method is based on solving Poisson's equation inside the structure. Poisson's equation can be written as:

$$\Delta u = -1 \qquad \textbf{(I)}$$

where u is the potential function. The length of each streamline, which follows the gradient of u and calculated by summing the Euclidean distances between neighboring points along the streamline, is called displacement ("electrostatic displacement" in Mathematical Physics). The variation of displacement decreases from one equipotential level to another while moving towards the one sink point. Using this approach, each shape can be associated with one scalar called 'the critical energy' E_0 ,which represents the amount of energy corresponding to the variance near zero. Thus, E_0 consists of the amount of energy needed to transform the shape into a sphere.

3 Results

To investigate the difference in volumes in the caudate head between the infants with and without WMI in the two groups, we performed a one way ANOVA test. As expected, found a significant difference in caudate volume between the two sides in infants with asymmetric WMI ($p<0.001$). We also found a significant difference between the volume of the injured side of infants with WMI and each of the right and left sides of NI infants ($p<0.001$). We were not able to find any significant difference in volume between the caudate head from the unaffected side of the infants with WMI when compared with the either caudate nuclei of the NI group. Next, we applied our novel method to investigate whether there was any difference in shape of the caudate head between the two groups of infants, and between sides. We used trilinear interpolation to increase the resolution of the segmented data. Thereafter, Poisson's equation was solved for each left and right caudate head independently. The displacement maps were calculated using the algorithm presented in Methods section. We determined the critical point at $v = 10\%$. Our test revealed a statistically significant difference in the shape of the injured side in infants with WMI when compared with the contralateral side ($p<0.015$). Moreover, we also found a statistically significant difference in the shape of the injured caudate head of the WMI group when compared with either caudate head of the NI group ($p<0.01$). Notably, we also found a statistically significant difference in shape between the *unaffected* side of the WMI group and either caudate of the NI group ($p<0.01$). No significant difference in the shape of the caudate head was found between the left and right sides in the NI group.

4 Conclusions

We applied our new method for shape analysis of anatomical structures to study the shape of the caudate nucleus of premature newborns. To our knowledge, this is the first study of shape of caudate nuclei of preterm babies. Our method is based on using the solution of Poisson's equation to assess the dynamics of the change of shape of the equipotential surfaces inside the structure. Our preliminary results revealed significant differences in the shape of the caudate nucleus, not only in the nuclei obviously affected by an ipsilateral hemorrhagic infarction, but also in the contralateral caudate in infants with WMI. These findings demonstrate the power of this novel method to detect changes in the shape of a structure (caudate nucleus), even when there is no difference in the volume when compared with normal controls. This technique will likely help elucidate the sometimes subtle anatomical changes in structures affected directly or even at a distance by disease processes such as ischemic brain injury.

Acknowledgments

We would to thank the William Hearst Foundation (HH), NIH grant P01-NS38475 (JSS and AJP) and the United Cerebral Palsy Foundation (JSS) for support of this work.

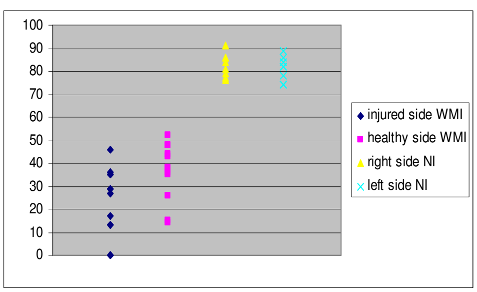

Figure 1. Plot representing the critical energy E_0 for each subject of both sides of different groups: injured side WMI, healthy side WMI, right side NI and left side NI.

References

1. Volpe, J. (2001). Neurology of the newborn. W.B. Saunders Co., Philadelphia.
2. Inder, T. E., P. S. Huppi, et al. (1999). "Periventricular white matter injury in the premature infant is followed by reduced cerebral cortical gray matter volume at term." Ann Neurol 46(5): 755-60.
3. Peterson, B. S., B. Vohr, et al. (2000). "Regional brain volume abnormalities and long-term cognitive outcome in preterm infants." Jama 284(15): 1939-47.
4. Abernethy, L. J., M. Palaniappan, et al. (2002). "Quantitative magnetic resonance imaging of the brain in survivors of very low birth weight." Arch Dis Child 87(4): 279-83.
5. Haidar H, , Bouix S., Levitt J. , Dickey C., McCarley R. W. , Shenton M.E. and Soul JS. 2004. Characterizing the shape of anatomical structures with Poisson's equation. In Proceedings of The Seventh International Conference on Medical Image Computing and Computer-Assisted Invervention. Rennes, France, 2004.
6. Levitt, J.J., et al., MRI Study of Caudate Nucleus Volume and Its Cognitive Correlates in Neuroleptic-Naive Patients With Schizotypal Personality Disorder. American Journal of Psychiatry, 2002. 159: p. 1190-1197.