

Volume and shape analysis of the caudate in ADHD adults

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Introduction: Attention deficit hyperactivity disorder (ADHD) is a developmental psychiatric disorder that is characterised by the symptoms hyperactivity, impulsivity and inattention. Affecting approximately 4% of children, 35%-60% of subjects with ADHD continue to exhibit symptoms into adulthood.¹⁻³ Children with ADHD have been shown in a number of neuroanatomical MRI studies to have brain volume reductions occurring in several grey matter regions including the caudate nucleus.⁴⁻⁸ While caudate volume reductions in children have been observed to effectively normalize by adulthood, the abnormal perfusion in the caudate both persists into adulthood and responds to treatment with stimulant medications^{9,10}. The purpose of this study was to analyse caudate shape and volume measurements in order to investigate the neuro-developmental differences between ADHD adults and age-matched controls, and to evaluate any associations between shape and volume and ADHD symptoms scores.

Methods: The subject group consisted of 10 male patients (mean age 31 years, range 20-48) who fulfilled the DSM-IV criteria for ADHD with no history of co morbid neurological or psychiatric illness.¹ These patients had no history of substance abuse, were clinically responsive to stimulant treatment, and used no other prescription drugs. ADHD symptom scores were obtained using the Barkley symptom checklist both on and off treatment. Seventeen healthy males (mean age 30 years, range 22-42), with no history of neurological or psychiatric illness were used as controls. Both structural dual echo FSE and volumetric fast IR-SPGR images were acquired with a 1.5 T GE Signa Echospeed MRI scanner (GE Medical Systems, Milwaukee, WI, USA). The caudate edge was defined using the GM maps segmented from the dual echo images, and the overall caudate surface area (SA), volume (Vol), and surface area to volume ratio (SA/V) were determined. Comparisons between ADHD and control subjects were conducted using Mann-Whitney U tests with significance determined against Monte-Carlo generated distributions (10000 replacements). Correlations between the caudate volume and shape measures were investigated using Spearman's rho. The statistical analyses were performed with SPSS version 15 (SPSS Inc, Chicago, IL, USA).

Results: The average caudate volume, surface area, and ratio measures are given in table 1, and examples of the segmented caudate nuclei from a representative ADHD patient and control subject are shown in figure 1. Significant laterality differences emerged for all three measures of both groups ($p < 0.013$, paired t-tests), with caudate volume and surface area greater on the right, and SA/V ratio greater on the left. While volume and surface area showed no significant differences between the groups, the ADHD group demonstrated a significantly higher SA/V ratio in the right caudate relative to the controls ($p < 0.05$, $p = 0.16$ right and left respectively). Correlations between the caudate shape measures in the ADHD group and the symptom scores from the Barkley symptom checklist are shown in table 2. The unmedicated hyperactive/impulsive scores showed strong significant relationships on the left side which were positive for the volume, surface area and negative for the SA/V ratio ($r_s = 0.70$, $p < 0.024$; $r_s = 0.67$, $p = 0.035$; $r_s = -0.84$, $p = 0.002$, respectively).

Discussion: The volume measures are in good agreement with those reported previously.¹¹ While no significant differences in caudate volume were seen between groups, the caudate shape SA/V was higher for the ADHD group. The significant correlation observed between unmedicated hyperactive/impulsive symptom score and SA/V ratio suggests that ADHD symptoms are associated with neuroanatomical differences in caudate development.

Table 1. Mean SA (mm^2), Vol (mm^3), and SA/V (mm^{-1}) across the subject groups

	SA (left)	SA (right)	Vol (left)	Vol (right)	SA/V (left)	SA/V (right)
ADHD	2186	2417	4590	5267	0.49	0.47
Control	2155	2269	4618	5159	0.47	0.44



Table 2. Correlations between caudate SA, Vol, and SA/V and symptom scores (Spearman's rho).

	SA (left)	SA (right)	Vol (left)	Vol (right)	SA/V (left)	SA/V (right)
Hyp/Imp (med)	.53	.35	.58	.41	-.58	-.46
Hyp/Imp (unmed)	.67(*)	.44	.70(*)	.43	-.84(**)	-.56

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

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Figure 1. Segmented caudate nuclei from a representative ADHD patient (left) and healthy volunteer (right).