# Bicaudate ratio as a measure of caudate volume on MR images.

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# Bicaudate Ratio as a Measure of Caudate Volume on MR Images

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**Many studies have used ratios based on intercaudate distance as a measure of caudate atrophy and ratios based on bifrontal distance as a measure of ventricular enlargement independent of caudate atrophy. The purpose of the current study was to determine to what extent these ratios correlate with caudate area and volume and frontal horn area in various groups of patients. The three linear ratio measures, obtained from MR scans, were bicaudate ratio, bifrontal ratio, and bifrontal distance divided by bicaudate distance. Area and volume measures were corrected for brain size. Subjects included patients with autism, obsessive-compulsive disorder, and Huntington disease, as well as normal controls. As expected, the patients with Huntington disease had the largest bicaudate ratio, bifrontal ratio, and frontal horn area. Both bicaudate ratio and bifrontal ratio were fairly good measures of frontal horn size for most groups. Consistent with theoretical expectations, the bifrontal ratio was not highly correlated with caudate area or volume ratios. Bicaudate ratio and bifrontal distance/bicaudate distance were correlated with caudate volume for the patients with Huntington disease, but not for any of the other groups. Bifrontal distance/bicaudate distance was the best single predictor of caudate volume for all groups combined.**

**It is concluded that bicaudate ratio and bifrontal distance/bicaudate distance are fairly good measures of caudate *atrophy*, but are poor measures of caudate *size* when no atrophy is present.**

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As early as 1942, Evans [1] developed a ratio of linear measurements to estimate the amount of ventricular enlargement in the pneumoencephalogram. With the advent of CT scans, several similar ratios were developed. Those most commonly used involve measurement of the intercaudate distance (CC), the bifrontal distance (FH), and some estimate of brain width to correct for overall brain size. The ratios that have been used include the bicaudate ratio (BCR): the intercaudate distance divided by the distance between the *inner* tables of the skull at the intercaudate line [2–7]; $CC/IT_{max}$ or CC/SD: the intercaudate distance divided by the maximal internal skull diameter [8–11]; $CC/OT_{CC}$: the intercaudate distance divided by the distance between the *outer* tables of the skull at the intercaudate line [11–15]; the bifrontal ratio (BFR): the bifrontal distance divided by the distance between the *inner* tables of the skull at the bifrontal line [2–6, 16]; FH/SD: the bifrontal distance divided by the maximal internal skull diameter [8, 9, 17]; $FH/OT_{FH}$: the bifrontal distance divided by the distance between the *outer* tables of the skull at the bifrontal line [15]; FH/CC: and the bifrontal distance divided by the intercaudate distance [8, 10–12, 14, 15, 18–22].

Several studies have been undertaken to explore differences in the BCR and BFR measures between various patient groups and normal controls. Patients with Huntington disease (HD) have been studied most frequently because of the caudate atrophy that is known to occur in this disease. All studies comparing HD patients with normal control subjects have shown significant differences in the ratios

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involving bicaudate distance [4, 8, 10, 12, 17, 18, 22]. Some have shown significant correlations between BCR measures and duration of disease [4, 8, 21], while others have not [17, 18]. Some investigators have found correlations between bicaudate measures and some indexes of symptom severity [3, 7, 11, 15, 17]; others have not [8, 18].

Some studies examining *bifrontal* measures in HD patients and normal control subjects have found significant group differences [4, 17] and correlations with symptom severity [17] and duration [4], while others have found no group differences [8] or correlations with duration [17] or symptom severity [3, 15]. Studies have also examined bifrontal and bicaudate measures in normal subjects [23, 24] and other patient groups, including individuals with tardive dyskinesia [19, 20, 25], schizophrenia [2, 5, 26], Down syndrome [6], alcoholism [27], dementia [16, 28], and amyotrophic choreoacanthocytosis [14].

In these studies, ratio measures involving bicaudate distance (BCR, CC/$OT_{CC}$, CC/SD, FH/CC) are generally assumed to reflect caudate atrophy, while ratios based on frontal horn distance divided by brain width are generally assumed to reflect enlargement of the frontal horns independent of caudate atrophy [15]. These assumptions have never been empirically tested, however, and it is possible that widening of the intercaudate distance may, at least in some cases, reflect only ventricular enlargement without caudate atrophy. The purpose of this study was to determine the extent to which the BCR and BFR reflect caudate atrophy and/or overall ventricular enlargement in various patient groups.

## Subjects and Methods

### *Subjects*

The relationship between BCR, BFR, frontal horn area, and caudate size was examined in 25 normal individuals and four groups of patients with diseases that would be expected to show varying amounts of caudate atrophy: (1) 11 males 8–53 years old (mean, 29 years) with autism; (2) 13 men and six women 19–53 years old (mean, 35 years) with obsessive-compulsive disorder (OCD); (3) eight men and five women 30–61 years old (mean, 46 years) who had had HD for 4 years or less (mean duration of chorea, 2.3 years; range, 1–4 years); and (4) eight men and eight women 29–73 years old (mean, 47 years) who had had HD for more than 7 years (mean duration of chorea, 10 years; range 7–23 years). The control group included 25 normal subjects, 19 men and six women 18–62 years old (mean, 32 years). No attempt was made to match groups for age, sex, or other demographic variables.

Autism was diagnosed according to the algorithm of the Autism Diagnostic Interview [29] based on information provided by the mothers of the subjects. OCD subjects were outpatients, initially recruited for drug trials, who met DSM-III-R criteria for obsessive-compulsive disorder. The onset of symptoms occurred prior to the age of 18 years in all cases. Criteria for HD were (1) chorea or the characteristic impairment of voluntary movement, which was not present at birth, was insidious in onset, and had become gradually worse, and (2) a family history of at least one other member with these typical symptoms of HD. The age of onset and chorea was documented for each patient by interviewing an unaffected relative who lived with the patient. Normal control subjects were hospital employees and members of the surrounding community who responded to advertisements in hospital and local newspapers. Exclusion criteria were a history of psychiatric illness or CNS illness, head injury that caused unconsciousness for more than 1 hr, headaches of sufficient severity to have led to medical consultation, heavy alcohol or illicit drug use, oral steroid use in the preceding 3 months, or loss of 25% of more of original body weight in the past 12 months.

Scans for the autistic and OCD subjects were rated together with those from normal controls, so that the raters were blinded to the diagnostic status of the subjects. HD scans were rated separately, but raters were blinded to the duration of illness.

### *MR Scans*

All subjects were examined with a 1.5-T Signa MR scanner (General Electric, Milwaukee, WI). A sagittal series, 600/20/1 (TR/TE/excitations), was obtained first. A line connecting the anterior commissure and posterior commissure was drawn on the midsagittal slice (Fig. 1) and used for orientation of the remaining series. Proton-density-weighted (2500/30/1) and T2-weighted (2500/80/1) axial sections were obtained through the entire brain, parallel to the anterior commissure–posterior commissure line, with 5-mm-thick interleaved slices and a field of view of 22–24 cm. All images were acquired with 256 × 256 spatial resolution and archived on nine-track magnetic tape.

### *MR Rating*

MR images were rated on a DEC Station 3100 graphics workstation (Digital Equipment Corp., Maynard, MA), which has 24 megabytes of CPU memory, a graphics coprocessor, and 6 bits of user-controlled color. MR tapes were initially read on a nine-track tape drive and archived on either a cassette tape subsystem or a read/write optical disk. Images were then displayed for rating on a 19-in. (48-cm) color monitor. Display from magnetic tape was chosen to avoid differences introduced by film processing and to take maximum advantage of image data. Custom graphics software was developed locally by using X Windows [30]. Slices containing regions of interest were first identified on MR hard-copy images. Corresponding cuts were then displayed on the graphics workstation, and interactively outlined with a mouse-controlled cursor. Image display tools included facilities for changing image contrast and brightness and a variable zoom feature, which employed bilinear interpolation to avoid aliasing, as well as facilities for storage and for editing of regions of interest.

Volumetric measurements were completed by one of the authors, a neuropsychologist with training in neuroimaging research. The linear and area measurements were completed by a medical student.

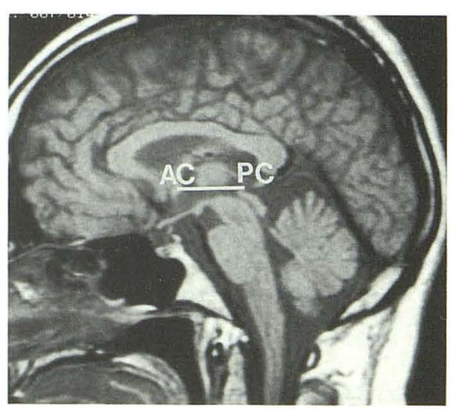



**Fig. 1.—Anterior commissure (AC)–posterior commisure (PC) line on midsagittal MR section (600/20/1).**

Measurement methods had been reviewed by a neuroradiologist. Raters were blinded to diagnoses of patients.

The validity of volumetric measures was estimated with a realistic anatomic phantom that was based in a human skull with the calvaria replaced by a plastic shield. The phantom contained balloons that were of the correct morphology, in the correct coordinates, and of approximately the same volume as the basal ganglia. Each balloon was filled with a known volume of a dilute solution of gadopentetate dimeglumine. The balloons were surrounded by a different dilution of gadopentetate dimeglumine. The phantom was scanned on the same MR scanner with scan parameters identical to those used for the subjects. Volumes were calculated from the scans by using the method already described. Correlations of actual volumes and volumes obtained from the scans were excellent ($r > .92$ in every instance) [30].

### Measurements

*BCR.*—BCR was obtained from the T2 axial section in which the frontal horns were clearly visible and the septum was the thinnest. The BCR was obtained by dividing the minimal distance between the caudate indentations of the frontal horns by brain width along the same line. The BCR was measured independently by two raters on 10 scans. The slices on which the BCR was measured were chosen by consensus. The interrater reliability coefficient was .97 for this measure, and a paired t test revealed no significant differences between the means obtained by the two raters.

*BFR.*—The BFR was measured on the same T2 axial section as the BCR and was defined as the distance between the most lateral tips of the frontal horns, divided by brain width along the same line. The BFR was measured independently by two raters on 10 scans, resulting in an interrater reliability coefficient of .99, with no significant difference between the means for the two raters.

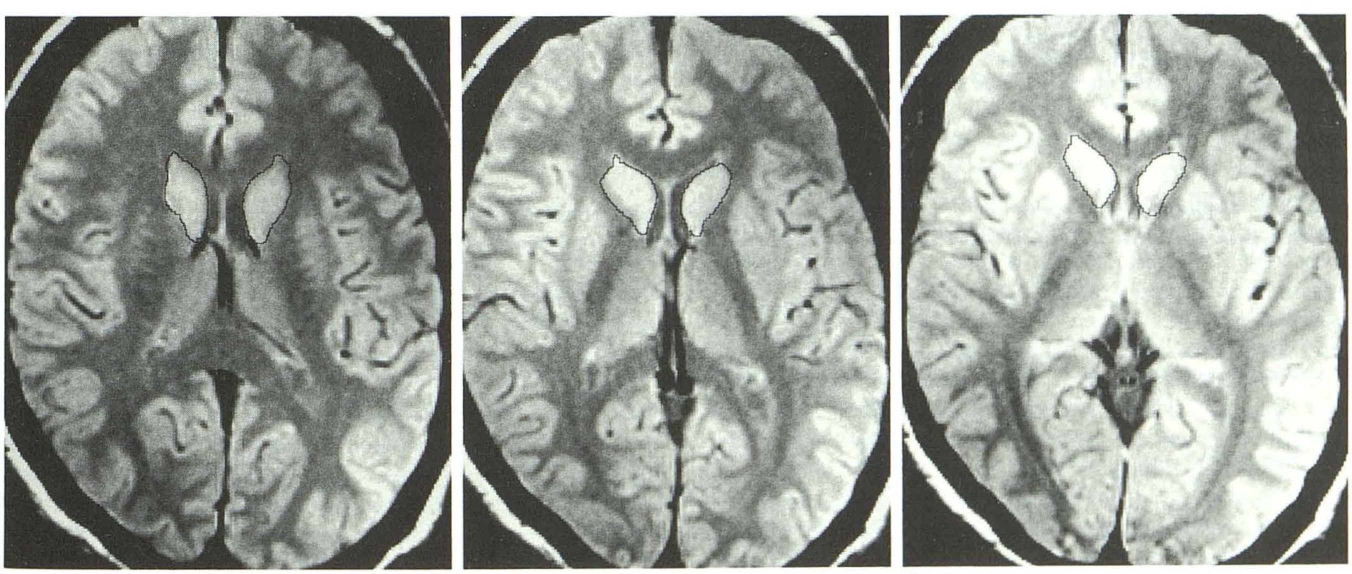
*FH/CC.*—Because several previous investigators [8, 10–12, 14, 18–22] have used this ratio, it was calculated as well.

*Caudate area and volume ratios.*—The axial proton-density sections were used for caudate area and volume measurements. The perimeters of the caudate were traced, beginning at the level immediately superior to that in which the anterior commissure was observed. Measurement continued superiorly through the level just below that in which the body of the caudate was observed (Fig. 2). In most cases, the caudate was contained on three slices, but in some cases (especially within the HD groups), only one or two levels were observed to contain caudate.

The borders of the caudate (Fig. 2) were defined laterally by the anterior limb of the internal capsule and medially by the frontal horn or body of the lateral ventricle. The bed nucleus of the stria terminalis (posterior to the caudate) was not included, even though it was often of the same density as the caudate.

Two raters independently identified the slices in which the caudate was to be measured. They agreed on the exact slices to be included in 83% of cases, and disagreed on inclusion of one slice in the remaining 17%. In the latter cases, the raters agreed on the slices to be included before any measurements were made. Caudate volume was calculated by summing the areas from all slices in which caudate was measured and multiplying this sum by slice thickness (5 mm). To correct for overall brain size, caudate area and volume were divided by brain area on the slice on which BCR and BFR were measured and multiplied by 100, producing caudate area and caudate volume ratios. Twelve scans were measured independently by two raters, resulting in an interrater reliability coefficient of .99 for caudate volume and of .93 for area measured in the single slice. Interrater reliability for measuring brain area was .99, based on 10 scans. Paired t tests revealed no significant differences between means obtained by the two raters for caudate volume, caudate area, or brain area. In addition, the area of the caudate on the slice on which BCR and BFR were measured was recorded separately.

*Frontal horn ratio.*—Frontal horn area was measured on the same T2 axial section as the BCR and BFR, as demonstrated in Figure 3. The frontal horn ratio was obtained by dividing the total area of the frontal horns by brain area and multiplying by 100. The frontal horn ratio was measured independently by two raters on 10 scans. Inter-



A B C

**Fig. 2.—Measurement of caudate volume on MR images (2500/30/1).**
***A*, Most superior slice in which caudate was measured was just inferior to slice in which body of caudate was observed.**
***B*, Second slice of caudate measurement.**
***C*, Most inferior slice in which caudate was measured was just superior to slice containing anterior commissure.**

rater reliability was .98, with no significant differences between the means for the two raters.

In a very small number of cases it was not possible to obtain all linear, area, and volume measures. This generally occurred for the measures that required a clear view of the entire frontal horn (BFR, FH/CC, and frontal horn area). In the few cases lacking these measures, the more posterior portion of the frontal horn was clearly delineated, but the anterior tips were obscured because of the angle of the slice. For one HD subject, no caudate was observable in the section used for measuring BCR, BFR, and FH/CC. Even though a caudate volume was measured for this subject, no caudate area measure could be obtained, since caudate area was always measured on the same slice as the BCR, BFR, and FH/CC. The number of cases in which each measure was obtained is presented in Table 1.

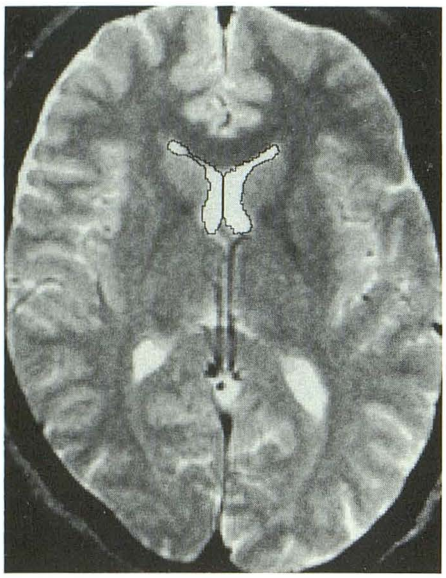


**Fig. 3.—Measurement of frontal horn area on MR image (2500/80/1). Area of frontal horns was measured on slice where bicaudate ratio, bifrontal ratio, and bifrontal distance/bicaudate distance were obtained. This is slice in which frontal horns are clearly visible and septum is thinnest.**

## Results

Table 1 gives mean BCR, BFR, FH/CC, frontal horn ratios, caudate area ratios, and caudate volume ratios for all subjects combined, normal control subjects, HD subjects, OCD subjects, autistic subjects, all non-HD subjects, subjects with HD for 4 years or less, and subjects with HD for more than 7 years.

Analyses of variance that used diagnosis (autistic, HD, OCD, normal) as the independent variable indicate group differences for BCR ($F = 60.67$, df = 3,81, $p < .00001$), BFR ($F = 4.34$, df = 3,79, $p < .007$), FH/CC ($F = 28.71$, df = 3,79, $p < .00001$), frontal horn ratio ($F = 20.48$, df = 3,79, $p < .00001$), caudate area ratio ($F = 76.65$, df = 3,80, $p < .00001$), and caudate volume ratio ($F = 37.75$, df = 3,83, $p < .00001$). Scheffe's post hoc analysis [31] indicated that the HD group had significantly larger BCRs, smaller FH/CCs, smaller caudate area ratios, and smaller caudate volume ratios than any other group. The HD group differed from the OCD group only in BFR. No other group differences were noted for any of these variables.

t tests were computed to compare patients who had had HD for 4 years or less with those who had had HD for more than 7 years. The two groups differed only on caudate area ratio ($t = 2.14$, df = 26, $p = .04$) and caudate volume ratio ($t = 2.28$, df = 27, $p = .031$).

The BCR, BFR, and FH/CC ratio were correlated with caudate area ratio, caudate volume ratio, and frontal horn ratio for each of the eight groups listed in Table 1. Results of these correlations are presented in Table 2.

Frontal horn ratios were also correlated with caudate area and volume ratios for each of the eight groups. The correlation between frontal horn ratio and caudate area ratio was significant and in the expected direction only for the entire sample ($r = -.58$, $p < .0001$) and for the OCD group ($r = -.67$, $p \leq .001$). The correlation between frontal horn ratio and caudate volume ratio was significant only for the entire sample (r =

**TABLE 1: Ratios of Linear, Area, and Volume Brain Measures in Normal Control Subjects and Patient Groups**

| Group | Mean ± SD (Sample Size) | | | | | |
|---|---|---|---|---|---|---|
| | Bicaudate Ratio | Bifrontal Ratio | Bifrontal Distance/ Bicaudate Distance | Frontal Horn Ratio | Caudate Area Ratio | Caudate Volume Ratio |
| All patients and control subjects | 0.13 ± 0.05 ($n$ = 82) | 0.30 ± 0.04 ($n$ = 80) | 2.58 ± 0.86 ($n$ = 80) | 2.84 ± 1.32 ($n$ = 80) | 1.78 ± 0.50 ($n$ = 81) | 22.9 ± 9.8 ($n$ = 84) |
| Control subjects | 0.09 ± 0.02 ($n$ = 24) | 0.30 ± 0.02 ($n$ = 23) | 3.11 ± 0.68 ($n$ = 23) | 2.11 ± 0.67 ($n$ = 22) | 2.18 ± 0.26 ($n$ = 24) | 27.6 ± 6.8 ($n$ = 25) |
| Huntington disease | 0.18 ± 0.04 ($n$ = 29) | 0.32 ± 0.05 ($n$ = 29) | 1.76 ± 0.44 ($n$ = 29) | 4.00 ± 1.46 ($n$ = 29) | 1.20 ± 0.28 ($n$ = 28) | 12.8 ± 5.2 ($n$ = 29) |
| Obsessive-compulsive disorder | 0.10 ± 0.02 ($n$ = 19) | 0.29 ± 0.01 ($n$ = 19) | 2.91 ± 0.70 ($n$ = 19) | 2.26 ± 0.52 ($n$ = 19) | 1.99 ± 0.23 ($n$ = 19) | 29.6 ± 6.0 ($n$ = 19) |
| Autism | 0.09 ± 0.02 ($n$ = 10) | 0.29 ± 0.03 ($n$ = 9) | 3.19 ± 0.62 ($n$ = 9) | 2.16 ± 0.51 ($n$ = 10) | 2.05 ± 0.19 ($n$ = 10) | 27.7 ± 9.6 ($n$ = 11) |
| Not Huntington disease | 0.09 ± 0.02 ($n$ = 53) | 0.29 ± 0.02 ($n$ = 51) | 3.05 ± 0.68 ($n$ = 51) | 2.18 ± 0.58 ($n$ = 51) | 2.09 ± 0.25 ($n$ = 53) | 28.3 ± 6.9 ($n$ = 55) |
| Huntington disease (duration ≤ 4 yr) | 0.18 ± 0.04 ($n$ = 13) | 0.33 ± 0.05 ($n$ = 13) | 1.87 ± 0.57 ($n$ = 13) | 4.37 ± 1.85 ($n$ = 13) | 1.31 ± 0.03 ($n$ = 13) | 15.1 ± 5.3 ($n$ = 13) |
| Huntington disease (duration > 7 yr) | 0.18 ± 0.03 ($n$ = 16) | 0.31 ± 0.04 ($n$ = 16) | 1.67 ± 0.28 ($n$ = 16) | 3.70 ± 1.02 ($n$ = 16) | 1.10 ± 0.28 ($n$ = 15) | 10.9 ± 4.5 ($n$ = 16) |

**TABLE 2: Bicaudate Ratio, Bifrontal Ratio, and Bifrontal Distance/Bicaudate Distance Correlated with Caudate Area Ratio, Caudate Volume Ratio, and Frontal Horn Ratio**

| Ratio/Group | Correlation Coefficient (No. of Subjects) | | |
|---|---|---|---|
| | Caudate Area Ratio | Caudate Volume Ratio | Frontal Horn Ratio |
| Bicaudate ratio | | | |
| All patients and control subjects | −.82[a] (81) | −.74[a] (82) | .84[a] (80) |
| Control subjects | −.06 (24) | .14 (24) | .61[b] (22) |
| Huntington disease | −.54[c] (28) | −.53[b] (29) | .72[a] (29) |
| Obsessive-compulsive disorder | −.73[a] (19) | .11 (19) | .71[a] (19) |
| Autism | .18 (10) | .08 (10) | .77[c] (10) |
| Not Huntington disease | −.26[d] (53) | .11 (53) | .65[a] (51) |
| Huntington disease (duration ≤ 4 yr) | −.47 (13) | −.48[d] (13) | .74[c] (13) |
| Huntington disease (duration > 7 yr) | −.72[b] (15) | −.68[c] (16) | .80[a] (16) |
| Bifrontal ratio | | | |
| All patients and control subjects | −.23[d] (79) | −.37[a] (80) | .72[a] (79) |
| Control subjects | .35[d] (23) | .33 (23) | .29 (22) |
| Huntington disease | −.02 (28) | −.28 (29) | .82[a] (29) |
| Obsessive-compulsive disorder | .14 (19) | −.15 (19) | .08 (19) |
| Autism | .39 (9) | −.31 (9) | .80[c] (9) |
| Not Huntington disease | .34[c] (51) | .01 (51) | .31 (50) |
| Huntington disease (duration ≤ 4 yr) | −.02 (13) | −.32 (13) | .88[a] (13) |
| Huntington disease (duration > 7 yr) | −.22 (15) | −.49[d] (16) | .74[b] (16) |
| Bifrontal distance/bicaudate distance | | | |
| All patients and control subjects | .77[a] (79) | .65[a] (80) | −.65[a] (79) |
| Control subjects | .21 (23) | .02 (23) | −.42[d] (22) |
| Huntington disease | .60[a] (28) | .54[b] (29) | −.30 (29) |
| Obsessive-compulsive disorder | .77[a] (19) | .01 (19) | −.66[b] (19) |
| Autism | −.03 (9) | .11 (9) | −.52 (9) |
| Not Huntington disease | .39[c] (51) | .03 (51) | −.52[a] (50) |
| Huntington disease (duration ≤ 4 yr) | .62[d] (13) | .61[d] (13) | −.36 (13) |
| Huntington disease (duration > 7 yr) | .61[c] (15) | .36 (16) | −.42 (16) |

[a] $p \leq .0001$.
[b] $p \leq .001$.
[c] $p \leq .01$.
[d] $p \leq .05$.

−.58, $p < .0001$) and for the subjects who had had HD for more than 7 years (r = −.49, $p < .05$).

A multiple regression that used all subjects was computed to determine which of the linear measures best predicted caudate volume ratio. By using a stepwise procedure, the FH/CC variable was the first variable to be entered, resulting in a multiple r of .54 ($p = .002$). The other two linear measures, BCR and BFR, did not contribute significantly to the prediction after FH/CC was entered.

## Discussion

The significant differences between the HD group and all other groups for BCR, FH/CC, caudate area ratio, caudate volume ratio, and frontal horn area ratio confirm the known caudate atrophy in these patients. On the BFR, HD subjects differed only from the OCD group, which is fairly consistent with the view that BFR is a measure that is independent of caudate atrophy. It is not clear, however, why the OCD group measured significantly less than the HD group on this measure while other patient groups did not. The significant differences between subjects with HD for 4 years or less and those with HD for more than 7 years for caudate area ratio and caudate volume ratio, but not for any of the linear measures, suggest that the area and volume ratios are more sensitive than the linear ratios to caudate atrophy. When possible, therefore, the area or volume ratios are preferred to linear ratios, especially when subtle differences are expected. For example, in this data set, duration of illness was significantly correlated with caudate area ratio (r = −.43, $p = .012$) and volume ratio (r = −.52, $p = .002$), but not with any of the linear measures (r values for BCR, BFR, and FH/CC ranged from .07 to −.25). Had BCR been used as the measure of caudate atrophy, the finding of a significant increase in atrophy with duration of disease would have been missed. (As noted in the introduction, findings have been equivocal regarding the relationship between BCR and duration, as well as between BCR and other clinical and neuropsychological variables.)

As can be seen from the correlation coefficients in Table 2, BCR is consistently a good measure of frontal horn area. For all groups studied, BCR becomes larger as frontal horn area (corrected for brain size) becomes larger. BCR is related to caudate area ratio (which is derived from the same slice as BCR) for some groups but not others. The relationship is strongest for all subjects combined, followed by OCD subjects and subjects with HD for more than 7 years. BCR is not a particularly good measure of caudate *volume*, however, except in those groups that contain HD patients. As can be seen from Table 1, it is in these groups that the smallest mean caudate volumes were observed. Furthermore, the relationship is considerably stronger for those HD subjects with longer duration of symptoms (and smaller caudate volumes) than for those with shorter duration.

BFR is a fairly good measure of frontal horn size for most groups but is not highly correlated with caudate area or volume ratios. Significant *positive* correlations between caudate area and BFR were actually found for two groups (non-HD and normal controls), suggesting that *larger* BFRs are associated with larger caudate area ratios in some populations.

The FH/CC ratio is significantly correlated with the caudate area ratio for all groups except normal controls and autistic subjects, and is significantly correlated with caudate volume ratio for all subjects combined, all HD subjects combined, and subjects with HD for 4 years or less.

The correlations between caudate volume ratio and BCR are consistently (although only slightly) higher than the correlations between caudate volume ratio and FH/CC. However, when BCR, BFR, and FH/CC were entered into a multiple regression to predict caudate volume ratio, the FH/CC was the best single predictor, and the addition of the other two variables did not significantly improve the prediction. It should be noted that BCR is more highly correlated with frontal horn ratio than with caudate volume ratio or caudate area ratio. This is not consistently true for the FH/CC measure, suggesting that this measure does control somewhat for the size of frontal horns (as would be expected, since FH/CC includes the bifrontal distance in its calculation).

BCR and FH/CC are generally somewhat more highly correlated with caudate area ratio than with caudate volume ratio. This would be expected, as the caudate area measure was taken in the same slice as the bicaudate and bifrontal measures.

In summary, the linear measures (BCR, BFR, and FH/CC) are significantly correlated with caudate volume ratio for those

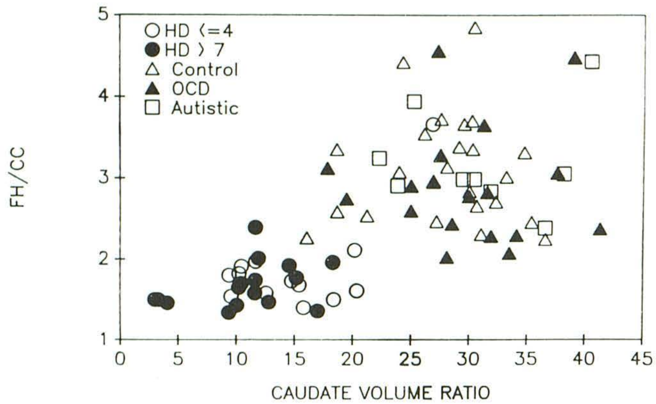



**Fig. 4.—Correlation between bifrontal distance/bicaudate distance (FH/CC) and caudate volume ratio in all subjects. HD = Huntington disease, OCD = obsessive-compulsive disorder.**

groups that contain subjects with HD. Correlations between caudate volume ratio and the linear measures are consistently highest when all patients and controls are combined because this combination allows the greatest range of values for both linear and volume measures. As can be observed in Figure 4, the strong correlation between FH/CC and caudate volume ratio is greatly dependent on the large range of scores, which is in turn dependent on the great differences between the HD patients and other subjects for both linear and volume measures. As indicated in Table 2, when only non-HD patients are considered, the correlation between the linear measures based on intercaudate distance (BCR and FH/CC) and caudate volume ratio are not significant and not in the expected direction. Thus, BCR and FH/CC should be considered to be measures of caudate volume only in patients with caudate atrophy. In other words, investigators should consider BCR and FH/CC to be fairly good measures of caudate *atrophy*, but poor measures of caudate *size* when there is no atrophy.

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