

ASSESSMENT OF BICAUDATE INDEX VALUES IN SIALKOT, PAKISTAN ADULT POPULATION USING COMPUTED TOMOGRAPHY: A PROSPECTIVE CROSS-SECTIONAL STUDY

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Abstract

Background: The bicaudate index (BCI) is a dimensionless ratio derived from CT that is a linear radiological measurement calculated by dividing the minimum distance between the heads of the caudate nuclei by the maximum internal skull diameter at the same level. The BCI accounts for the variability in skull size between individuals; normalizing for head size, the BCI gives a reproducible and directly comparable measure of central ventricular expansion and caudate atrophy. It is important for diagnosis in a range of diseases such as cerebral atrophy, hydrocephalus, Huntington's disease, multiple sclerosis, cognitive decline, and is found to be increasing with age and disease load. Although clinically useful, age and sex-stratified normative CT reference values for BCI are not yet available for the adult population of Pakistan. Objective: To derive reference values of CT bicaudate index in normal adult population of Pakistan across different age and sex basis and to find out the effect of age and sex on BCI. Methods: This is a prospective cross-sectional study with duration of 6 months at Idrees Hospital, Sialkot, Pakistan. 140 healthy adults aged 18–80 years were enrolled using convenient sampling. Results: The overall mean BCI of 140 healthy Pakistani adults (70 males and 70 females) ranged from 0.09 – 0.16 (males and females). A strong positive correlation was found between age and BCI ($r_s = 0.731$, $p < 0.001$), with mean values rising progressively from 0.09 (SD = 0.01) in the youngest age group (18–20 years) to 0.16 (SD = 0.04) in the oldest (71–80 years). No statistically significant difference was detected between genders ($U = 2253.5$, $p = 0.409$) and the mean BCI for males and females were equal. Conclusion: This study introduces the first age-stratified normative CT values of BCI in normal adults of Pakistan. BCI with age was significantly elevated and not affected by sex showing that in routine interpretation of cranial CT age specific reference values are required for neurological screening in Pakistan.

INTRODUCTION

The bicaudate index (BCI) was first described in 1978 as the ratio of the width of the lateral ventricles at the level of the caudate nuclei heads to the skull diameter at the same axial CT level and was shown to significantly differentiate patients with Huntington's disease (BCI 0.209 ± 0.007), cerebral atrophy (0.121 ± 0.006), and neurologically normal controls (0.092 ± 0.003) (Barr et al., 1978). The BCI simultaneously reflects both lateral ventricular enlargement and volume loss of the caudate nuclei, and is a head size-independent measure of the minimum intercaudate distance, divided by the maximum inner skull diameter at the same axial slice (Dhok et al., 2020; Huang et al., 2025). This normalization property sets it apart from absolute linear measurements, which makes it directly comparable between individuals, irrespective of the size of their crania and making it especially suited for normative analysis at the population level.

The BCI has been applied to a variety of neurological disorders making it one of the most versatile CT derived ventricular indices in clinical practice. In Huntington's disease, it showed superiority in sensitivity and specificity over the bifrontal and third ventricular ratios in distinguishing patients from age-matched controls even in the early symptomatic phase (Starkstein et al., 1989). MRI measurement of the bicaudate ratio is one validated measure of global brain atrophy and is found to be correlated with disability in multiple sclerosis (Bermel et al., 2002). In population-based studies, the BCI is independently associated with cognitive performance on the Montreal Cognitive Assessment (MoCA) and its association with MoCA scores persists even after controlling for all other confounder variables, but the Evans Index does not (Del Brutto et al., 2016). Baseline BCI values for age groups can be used for longitudinal monitoring of ventricular dilatation in subarachnoid hemorrhage (Dupont & Rabinstein, 2013). Further, BCI and related LVIs have proven to be good correlates of total lateral ventricular volume and are suitable for practical use in resource-limited countries (Bao et al., 2016; Bourne et al., 2013).

BCI is greatly and progressively elevated with age, due to a progressive nature of caudate atrophy and central ventricular expansion. The BCI in normal volunteers (22-82 years) is positively correlated with age ($r=0.59$, $p<0.0001$) and caudate nuclei volume is negatively correlated with age ($r=-0.47$, $p<0.0005$), confirming that the BCI reflects true caudate structural degeneration across adulthood (Doraiswamy et al., 1994). Normative BCI data has been published for various populations, such as Central India (Dhok et al., 2020) that reported for 511 participants a mean BCI of 0.1121 with significant variation between age and sex and thus recommended population-specific BCI cut-offs for the older adults; also, Sudan (Mohammed & Hassan, 2022) and Nepal (Yadav & Yadav, 2025) and others (Alomar & Ghoneim, 2024). These inter-population variations are further evidence that BCI normative thresholds developed for one ethnic population are not safe to transfer to another. Normative data of CT-BCI is still not available for Pakistani adults. It was therefore the aim of this study to determine the first age- and sex-stratified CT normative BCI values in healthy population of Pakistan.

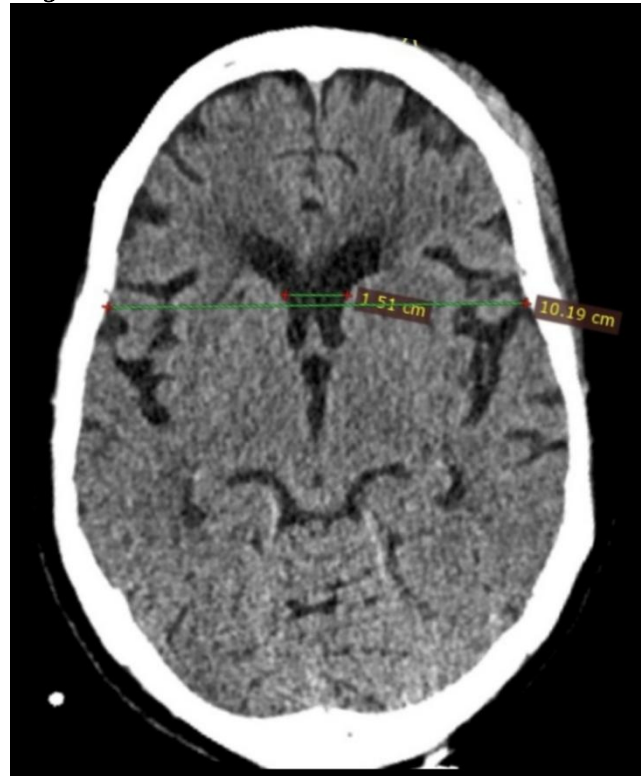
METHODS

The study was a prospective cross-sectional study for six months performed in Idrees Hospital, Sialkot, Pakistan, after obtaining the approval from the institutional review board and written informed consent from all the participants. Using a similar published study as a guide ($n = 108$), sample size was calculated by adding 25% for any potential attrition, and a total of 140 healthy adults (aged between 18-80) were conveniently sampled and also stratified into seven age groups (between 18-20, 21-30, 31-40, 41-50, 51-60, 61-70 and finally 71-80) for both sexes with each age group consisting of 10 participants. The non-contrast cranial computed tomography (CT) images were obtained at 5 mm axial slice thickness on a Toshiba Aquilion 16-slice multi-detector CT scanner and were processed using the software packages: RADIANT DICOM and Activision 16. BCI was determined as the intercaudate distance at the level of the caudate heads, divided by the maximum inner skull diameter at the same axial level. Participants with known space-occupying lesions, previous

neurosurgery, pregnant females, and those who had poor image quality because of intracranial pathologies distorting the normal anatomy of the ventricles were excluded. Data were analyzed through IBM SPSS Statistics v.25, the BCI-age

relationship was determined by using the Spearman's rank correlation, comparison between sex by Mann-Whitney U test and statistical significance was set at $p < 0.05$.

Fig 1: CT Slice showing methods to obtain measurements in order to calculate Bicaudate Index



RESULTS

A total of 140 participants were included in the analysis of the Bicaudate Index. A Spearman's rank correlation revealed a strong, statistically significant positive relationship between age and the Bicaudate Index ($r_s = 0.731$, $p < 0.001$, $N = 140$), indicating that older age is associated with higher Bicaudate Index values. Additionally, the Bicaudate Index showed a significant positive correlation with the Evans Index ($r_s = 0.598$, $p < 0.001$). Table 1 presents the mean Bicaudate Index across seven age groups ($n = 20$ per group). A clear progressive increase was observed from the youngest groups (Group 1: mean = 0.09, SD = 0.01; Group 2: mean = 0.09, SD = 0.01) to the oldest groups (Group 6: mean = 0.15, SD = 0.03; Group 7: mean = 0.16, SD = 0.04).

Intermediate groups showed generally progressive, with a slight non-significant dip in the 41–50 year's group (Group 3: mean = 0.12, SD = 0.02; Group 4: mean = 0.11, SD = 0.02; Group 5: mean = 0.12, SD = 0.02). Sex differences were assessed using the Mann-Whitney U test. No significant difference was found between females and males for the Bicaudate Index ($U = 2253.5$, $Z = -0.825$, $p = 0.409$). Descriptive statistics confirmed this finding, with both sexes showing identical mean values (male: mean = 0.12, SD = 0.03; female: mean = 0.12, SD = 0.03) (Table 2). Figure 2 illustrates the distribution of the Bicaudate Index across age groups separately for males and females. Both sexes followed a similar upward trend with increasing age, with no consistent sex-related divergence.

Table 1: *The Mean and SD of Bicaudate Index in respect to Age Groups*

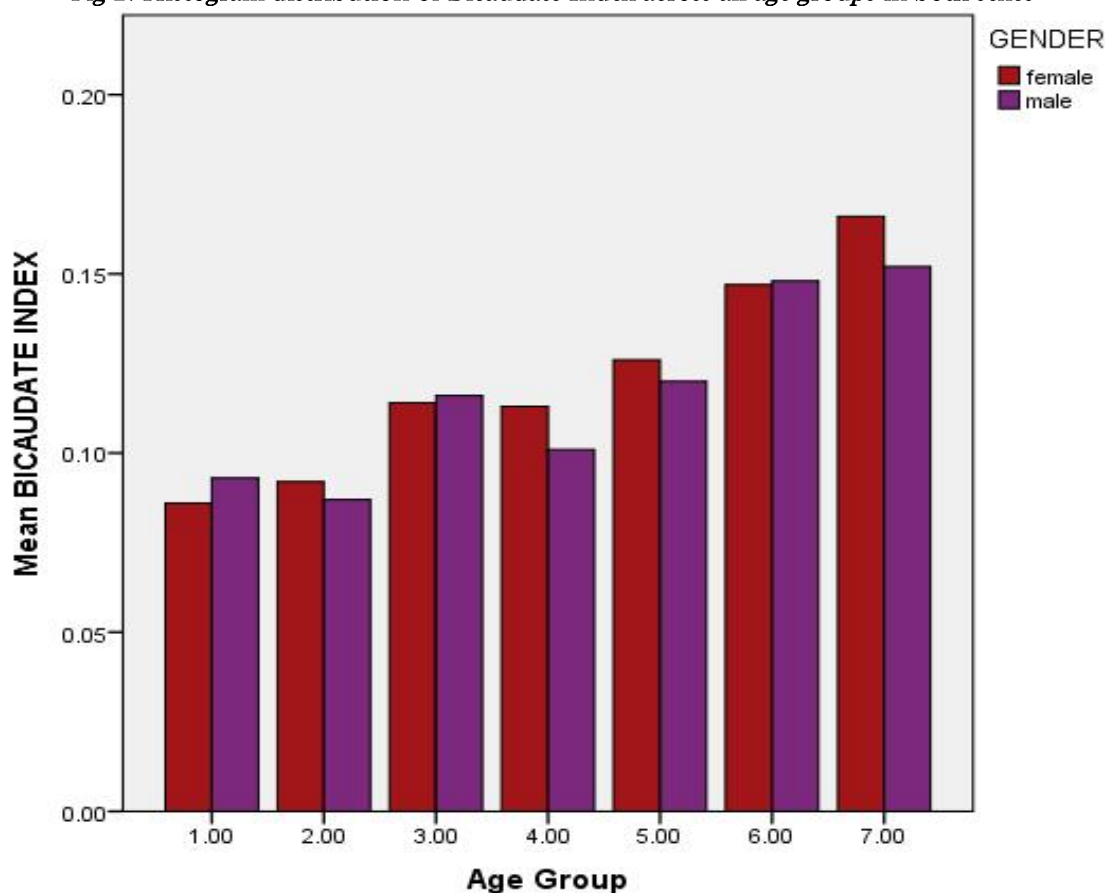
Age Groups	N	Mean	SD
1	20	0.09	0.01
2	20	0.09	0.01
3	20	0.12	0.02
4	20	0.11	0.02
5	20	0.12	0.02
6	20	0.15	0.03
7	20	0.16	0.04

SD: Standard Deviation

Table 2: *The Mean and SD of Bicaudate Index in respect to Sex*

Sex	N	Mean	SD
Male	70	0.12	0.03
Female	70	0.12	0.03

Fig 2: *Histogram distribution of Bicaudate Index across all age groups in both sexes*



DISCUSSION

Bicaudate Index is a well validated, head-size independent linear CT index that offers an easy way to assess both the degree of central ventricular enlargement and the presence of caudate nucleus atrophy in a single measurement and is therefore

useful in the resource limited clinical environment which lacks volumetric analysis. This increase of BCI with age is the same progress which has been observed in various populations. In a study of normal subjects (22-82 years), using MRI, the BCI was found to be significantly positively correlated

with age ($r = 0.59$, $p < 0.0001$) and the caudate nuclei volume was significantly negatively correlated with age ($r = -0.47$, $p < 0.0005$), thus supporting BCI as a valid reflection of true structural caudate degeneration over the spectrum of adult life (Doraiswamy et al., 1994). The biological basis of BCI differentiates it from the other linear ventricular indices. A normative study, based on a large number (1406) of CT scans, concluded that the upper limit of BCI of the first 3 decades of life was 0.13, then 0.15 at 4th decade, and 0.19 at the 5th decade with the BCI progressively doubling with participants older than 50 years (Kukuljan et al., 2009). The lack of sex difference in BCI in the present cohort is in keeping with the available structural neuroimaging data. A volumetric MRI study of 60 healthy adults showed no significant difference in caudate and putamen volumes between males and females, pointing to the insignificance of the relationship between sex and intercaudate distance variation in the absence of diseases (Elkattan et al., 2017). But there is some evidence that there are sex-related, regional differences in brain aging. It has been reported that the decline in grey matter volume in the caudate nucleus and putamen is greater in males and that the rate of decline is steeper than females (Park et al., 2024), this may be more evident in larger cohorts with older age cohorts than the present sample. Normative data for BCI is population specific as values differ between ethnic populations. According to the nearest published data, the Central Indian normative study, the mean BCI in the study participants was 0.1121 with statistically significant influence of both age and sex on BCI (Dhok et al., 2020). The mean BCI of 0.12 (SD = 0.03) for the overall mean in the present cohort of Pakistanis is broadly similar to this South Asian reference, although the lack of a sex effect in the present cohort is consistent with the small sample in each sub-group ($n = 10$) and may be attributable to reduced statistical power in detecting modest sex differences.

CONCLUSION

It is the first age stratified CT based normal reference values of BCI in healthy adult population of Pakistan, which shows that BCI mean is 0.12 (SD = 0.03) with age showing strong positive

correlation ($r_s = 0.731$, $p < 0.001$). Overall, BCI values increased with age, supporting previous observations of the presence of caudate atrophy and central ventricular dilatation as an integral part of normal ageing in this population. No significant sex-based difference was found, which is similar to the structural neuroimaging results which found no significant difference in the volumes of the caudate in healthy males and females. The result of the significant positive correlation of BCI with EI ($r_s = 0.598$, $p < 0.001$) further demonstrates that BCI can be used complementary to EI as a morphometry indicator of ventricles.

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