

EVANS INDEX IN A PAKISTANI ADULT POPULATION: A COMPUTED TOMOGRAPHY-BASED CROSS-SECTIONAL STUDY

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DOI: <https://doi.org/10.5281/zenodo.21450835>

Keywords:

Evans Index, Frontal Horn Width, Computed Tomography, Normal Pressure Hydrocephalus, Ventricular Enlargement, Normative Reference Values

Article History

Received on 20 Jan, 2026

Accepted on 16 Feb, 2026

Published on 19 Feb, 2026

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Abstract

Background: The Evans Index (EI), which is the ratio of the largest transverse diameter of the frontal horns to the largest internal diameter of the skull at the same axial level, is the most commonly used linear radiological ratio of ventricular enlargement used routinely in reporting of cranial CT scans. Globally, 0.3 has been used as a threshold for ventriculomegaly, and is incorporated in international guidelines for idiopathic normal pressure hydrocephalus (NPH) diagnosis. However, large-scale normative studies have shown that EI steadily rises with age and is systematically higher for males than females, making it insufficient to have a single cut-off threshold, without age and sex-specific reference values. There are no population specific normative CT EI data for Pakistani adults and Pakistani clinicians use data obtained from different ethnic populations. **Objectives:** To introduce different age and sex-specific normative values of Evans index for healthy population of Pakistan, and to determine the effects of age and sex on EI. **Method:** A prospective cross-section study was carried out in Idrees Hospital, Sialkot, Pakistan for 6 months. There were 140 participants in this study and they were healthy adults, ages 18–80 years, seven age groups ($n = 10$ for each sex group). **Results:** In healthy Pakistani adults (140 adults; 70 male and 70 female; age range 18–80 years) the mean Evans Index (EI) overall was 0.27 ($SD = 0.03$), and was not different between male and female groups. When the scores of EI were compared across the ages, a positive correlation was observed and it was found to be statistically significant ($r_s = 0.549$, $p < 0.001$), with mean scores showing increase gradually from 0.25 ($SD = 0.01$) in the youngest age group (18-20 years) to 0.30 ($SD = 0.04$) in the oldest age group (71-80 years). There was no significant difference between the EI mean scores of the males and the females in the sample (Mann-Whitney $U = 2216.5$, $p = 0.327$), and the mean scores were identical for the males and females across both sex groups. **Conclusions:** In this study, the normative CT value of Evans Index is set for the first time in a healthy adult population of Pakistan using an age stratification model. The EI increases with age and the influence of sex is not independent in this cohort. This indicates that the use of a single EI cut-off of ≥ 0.3 may not be clinically relevant for younger Pakistani adults; age-dependent EI reference standards should be used in the routine interpretation of cranial

INTRODUCTION

The Evans Index (EI) was first described by William A. Evans Jr. in 1942 as an encephalographic ratio to estimate the degree of ventricular enlargement; it was originally derived from pneumoencephalographic anteroposterior projections and was the ratio of the transverse diameter of the frontal horns to the widest transverse diameter of the skull (EVANS, 1942). After the introduction of CT imaging, this measurement was simply translated to the axial sections of the brain, and the ratio of the widest point of the lateral ventricles' frontal horns to the widest point of the skull's internal bone structure is now calculated on axial sections (Fleuren et al., 2025). The EI has been used in clinical practice for more than 80 years and, to date, it is the most widely used linear measurement of the ventricle size in routine neuroimaging all over the world; because of its simplicity, it can be easily reproduced, and there is no need for specially developed software.

The EI is its most crucial diagnostic use in the assessment of idiopathic normal pressure hydrocephalus (NPH) where ≥ 0.3 is established as the minimum radiological criterion for ventriculomegaly in international diagnostic guidelines (Relkin et al., 2005). But this threshold has been continuously critically reappraised. A large cross-sectional computed tomography (CT) study of 1,221 consecutive adult subjects (age 45 to 101 yrs) presenting to an emergency department showed that the average EI per annual age cohort was always lower than 0.3 in healthy normal aging and that EI values >0.3 were thus unlikely to represent the effect of normal aging alone and suggested that there is an age-related risk of values exceeding 0.3 (incorrectly attributed to normal aging) of 7.8% per year with males being at a 83.9% greater risk than females (Missori et al., 2016). The validity of using a fixed threshold as a diagnostic separator has been questioned, since a population-based study in the elderly (1235 adults ≥ 70 years) in Sweden has shown EI to range between 0.11 to 0.46, with 20.6% of these above the 0.3 threshold, and in male adults ≥ 80 years,

the mean EI has been 0.30 (Jaraj et al., 2017). To overcome these constraints, Brix and colleagues have proposed age and sex specific EI cut-offs, which were based on 534 healthy older adults and NPH patients; 29% of healthy controls had $EI \geq 0.3$; and new cut-offs of 0.34–0.37 for males and 0.32–0.36 for females across the consecutive age groups 65–84 years were proposed (Brix et al., 2017). Together, these results validate the need to develop locally derived EI reference values based on age and sex, and that a single universal cut-off of 0.3 is insufficient.

The EI is an extensively validated proxy of lateral ventricular volume. Studies based on MR image indicate that EI is correlated with ventricular volume (R^2 as high as 0.70), but still not perfect for each patient level, and both indices represent different aspects of the ventricle morphology (Ambarki et al., 2010). The measurements of linear EI have been specifically validated to three-dimensional volumetric measurements and proven to be representative of clinically meaningful outcomes in neurological conditions (Bourne et al., 2013; Dunham et al., 2016). The EI has also been used in the differential diagnosis between NPH and neurodegenerative diseases, with an area under the ROC curve of 0.956 for separating NPH from Alzheimer's disease (Toma et al., 2011) and in progressive supranuclear palsy and multiple system atrophy, where the EI and frontal horn widening help differentiate the two conditions (Kutyłowski et al., 2023). However, despite these advantages the EI is recognized to vary with the level of the axial scan from which measurements are taken and considerable inter-study variation in EI values have been reported based on different scanning baselines used (Huang et al., 2025). These methodological considerations also further highlight the need for the locally adapted and protocol specific normative data.

The EI rises with age as a consequence of enlargement of the frontal horns caused by the cerebral ageing process, and males have higher EI than females regardless of population (Brix et al., 2017; Ghorbanlou et al., 2024; Jaraj et al., 2017; Missori et al., 2016; Silva et al., 2025). CT

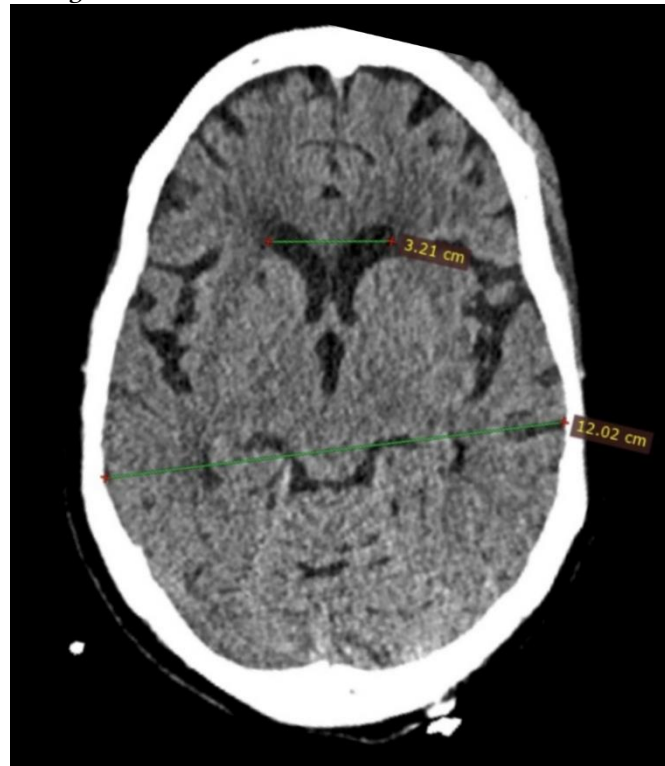
morphometric studies have been able to verify significant positive correlation between EI and age in normal population, and that sex difference in EI remains after age adjustment showing the sex difference to be largest in higher age levels (Ghorbanlou et al., 2024; Silva et al., 2025). In other populations, population specific normative CT EI datasets have also been established in Saudi Arabia (Alomar & Ghoneim, 2024), Central India (Dhok et al., 2020), Nepal (Yadav & Yadav, 2025) and Sudan (Mohammed & Hassan, 2022) and others (Gameraddin et al., 2015) with mean EI ranging between 0.2550 ± 0.0277 in the Saudi population and higher in older South Asian cohorts. These inter population differences suggest that EI normative levels are not interchangeable between ethnic groups. There are no normative EI data for adults in Pakistan obtained on the basis of CT. Therefore, the aim of this study was to produce the first normative EI values for healthy adult population of Pakistan based on CT and stratified by age and sex.

METHODS

A prospective cross-sectional study was carried out in Idrees Hospital in Sialkot, Pakistan for a period of six months. By convenient sampling a total of

140 healthy adults aged 18–80 years were enrolled and stratified into seven age groups (18–20, 21–30, 31–40, 41–50, 51–60, 61–70, and 71–80 years) for both sexes (n = 10 per sex per group). Non-contrast Cranial CT scans were taken with Toshiba Aquilion 16 slice multi-detector CT scanner with 5mm thickness axial images and analyzed on the computer using RADIANT DICOM software and Activision 16 software. The EI was determined and calculated as the maximum transverse diameter of the frontal horns/maximum internal diameter of the skull in the same axial plane with the built-in scale measure tool. Those with intracranial pathology which was distorting the normal anatomy of the ventricles, space occupying lesions, previous neurosurgery, pregnant females, poor image quality (no diagnosis could be made) were excluded. The data were analyzed in IBM SPSS Statistics v.25, descriptive statistics was presented in mean with standard deviation, correlation between EI and age was carried out using spearman correlation coefficient, comparison between the sexes was carried out using the Mann-Whitney U test and p value < 0.05 was considered statistically significant.

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



RESULTS

A total of 140 participants were included in the analysis of Evans Index. A Spearman's rank correlation revealed a statistically significant positive relationship between age and Evans Index ($r_s = 0.549$, $p < 0.001$, $N = 140$), indicating that older age is associated with higher Evans Index values. Differences between sexes were assessed using the Mann-Whitney U test. No significant difference was found between females and males for Evans Index ($U = 2216.5$, $Z = -0.980$, $p = 0.327$). Table 1 presents the mean Evans Index across seven age groups ($n = 20$ per group). A progressive increase was observed from the youngest group (Group 1: mean = 0.25, SD = 0.01)

to the oldest group (Group 7: mean = 0.30, SD = 0.04). Intermediate groups showed gradual elevation: Group 2 (mean = 0.25, SD = 0.03), Group 3 (mean = 0.27, SD = 0.02), Group 4 (mean = 0.27, SD = 0.02), Group 5 (mean = 0.28, SD = 0.02) and Group 6 (mean = 0.29, SD = 0.03). Descriptive statistics confirmed this finding, with both sexes showing identical mean values (male: mean = 0.27, SD = 0.03; female: mean = 0.27, SD = 0.03) (Table 2). Figure 2 illustrates the distribution of Evans 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 across the age groups.

Table 1: *The mean and SD of all groups in respect to Evans Index*

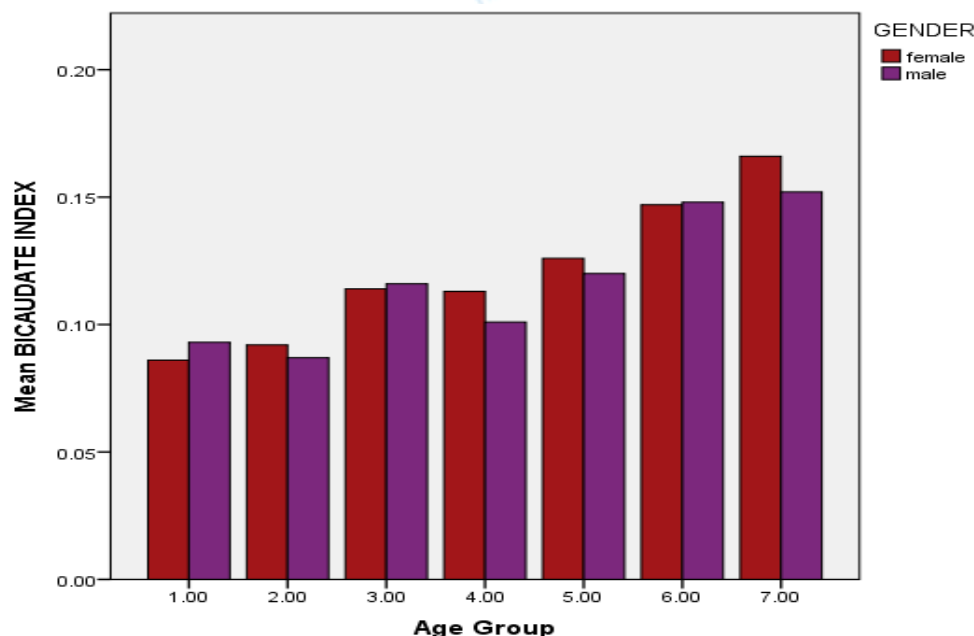
Age Groups	N	Mean	SD
1	20	0.25	0.01
2	20	0.25	0.03
3	20	0.27	0.02
4	20	0.27	0.02
5	20	0.28	0.02
6	20	0.29	0.03
7	20	0.30	0.04

SD: Standard Deviation

Table 2: *The mean and SD of both Gender in respect to Evans Index*

Sex	N	Mean	SD
Male	70	0.27	0.03
Female	70	0.27	0.03

Fig 2: *The distribution of Evans Index across all age groups in both sexes*



DISCUSSION

The Evans Index is a popular and convenient linear measurement of the size of the ventricles on CT that does not require specialized software. CT data correspond with large scale data and show a constant rise in EI with age in all groups and that values >0.30 indicate a neurological or atrophic state per se, and not aging alone (Missori et al., 2016). This age-related increase has been linked to progressive enlargement of the frontal horn due to cerebral atrophy and this phenomenon has been observed in various ethnic groups. The frontal horn was found to be the first compartment to be dilated with age, and a study of more than 3,000 CTs showed that abnormal enlargement of the ventricles (by EI criteria) was correlated with mean age of 79 years (Missori et al., 2016). Being a universal diagnostic standard, $EI \geq 0.3$ has been continuously criticized because of its low diagnostic value. Brix et al. discovered that 29% of healthy elderly controls were above 0.3 and suggested age- and sex-specific cut-off values ranging from 0.34-0.37 for male controls and 0.32-0.36 for female controls in the age range from 65-84 years (Brix et al., 2017). This is not a unique finding; another study done on the norm for CT in Nepal showed that there was not any statistically significant difference in EI between a male and female group ($p = 0.274$) (Yadav & Yadav, 2025). The need for population-specific normative data is widely recognized as the values for EI vary with ethnic and regional differences in cranial morphometry. The mean EI in the Saudi population was 0.2550 ± 0.0277 (Alomar & Ghoneim, 2024) whereas in geriatric people aged 70 years and above, Jaraj reported a mean EI of 0.28 (SD: 0.04) and the men of 80 years or more had the mean EI of exactly 0.30 which were similar to the present Pakistani population (Jaraj et al., 2017). Another methodological issue is that EI values may differ depending on the axial scan level at which it is measured (Huang et al., 2025), further emphasizing the need to standardize protocols with regard to normative data measured in other institutions.

CONCLUSION

This study is the first to report the age-stratified normative CT reference values of EI in healthy Pakistani adults and confirms a significant and

progressive increase of EI with age. This population only reaches the universally used EI cut-point for diagnosis ($EI \geq 0.3$) in the oldest age group (71-80 years), highlighting the lack of validity of a fixed cut-off across all adult age groups. No significant difference in EI was found between the sexes, which contrasts with some Western and geriatric samples. These population-specific normative data can be used to improve assessment of ventriculomegaly, screening for NPH and provide an update for the radiological reporting standards in Pakistan. Future studies with a large sample size within each age group and involving more centers are recommended to further validate and improve these reference values.

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