ORIGINAL ARTICLE

Magnetic Resonance Imaging Measurements of Corpus Callosum in Childhood; Determination of Normative Values

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ABSTRACT

Objective: *Corpus callosum (CC) has an important role in ensuring the transfer of information between homologous regions of hemispheres. Radiological anatomy of CC may contribute to diagnostic evaluation in children with neurological or syndromic diseases. Although previous studies exit on the dimensions of CC in different populations, only a few examined the reference sizes of CC in childhood. The aim of this study was to identify the normal dimensions of CC sub-regions using magnetic resonance imaging (MRI) in healthy children of all age groups and gender.*

Methods: *Among 14 852 cranial MRI performed from 2011–2013, 2753 images of children aged between 0–18 years were acquired. After exclusions, 493 images (boys/girls; 246/247) were included. The thickness of the genu, corpus, isthmus, splenium and antero-posterior diameter of CC was measured on MRI. This study was approved by the Research Ethics Committee of Gülhane Military Medical Academy.*

Results: *We demonstrated CC dimensions data of children from newborn to adolescent.*

Conclusions: *We think that it is important to determine the reference values of CC dimensions in healthy children in order to detect any deviation from normal. It is thought that these data can be applied in clinical practice.*

Keywords: Children, corpus callosum, MRI measurements, normative data

Mediciones de imagen por resonancia magnética del cuerpo calloso en la niñez; Determinación de los valores normativos

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RESUMEN

Objetivo: *El cuerpo calloso (CC) desempeña un papel importante en asegurar la transferencia de información entre las regiones homólogas de los hemisferios. La anatomía radiológica del CC puede contribuir a la evaluación diagnóstica en niños con enfermedades neurológicas o sindrómicas. Aunque los estudios previos provienen de las dimensiones de CC en diferentes poblaciones, sólo unos pocos examinaron los tamaños de referencia de CC en la niñez. El*

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objetivo de este estudio fue identificar las dimensiones normales de las subregiones de CC usando imágenes de resonancia magnética (IRM) en niños sanos de todos los grupos de edad y género.

Métodos: *De entre 14 852 imágenes craneales de IRM realizadas de 2011 a 2013, se tomaron 2753 imágenes de niños entre 0-18 años de edad. Después de algunas exclusiones, se incluyeron 493 imágenes (niños/niñas; 246/247). El grosor de la rodilla, el cuerpo, el istmo, el esplenio, y el diámetro anteroposterior del CC fueron medidos en el IRM. Este estudio fue aprobado por el Comité de Ética de la Investigación de la Academia Médica Militar de Gülhane.*

Resultados: *Demostramos datos de las dimensiones del CC de niños, desde recién nacidos hasta adolescentes.*

Conclusiones: *Creemos que es importante determinar los valores de referencia de las dimensiones del CC en niños sanos para detectar cualquier desviación de lo normal. Se piensa que estos datos pueden ser aplicados en la práctica clínica.*

Palabras clave: Niños, cuerpo calloso, mediciones de IRM, datos normativos

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INTRODUCTION

Corpus callosum (CC) is anatomically located between two cerebral hemispheres. Corpus callosum has an embriyological development in craniocaudal direction between 8–20 weeks of gestational life, but the rostrum forming finally adjacent to the genu of the CC (1). The microstructure of the CC, that is densely packed white matter, is also different from the other parts of the brain. Corpus callosum anatomically consists of five sections that are called; rostrum, genu, corpus, isthmus and splenium. Corpus callosum is the mainly inter-hemispheric commissure of the brain and composed of approximately 180 million fibres. Homologous regions on either side of the cortex are connected to each other with these fibres. Although the number of fibres do not rise after birth, but postnatal remodelling continues with myelination, pruning and redirection (2–4).

The functions of the CC are not entirely understood, yet. Corpus callosum is a particular anatomical structure that has an important role in ensuring the transfer of information between homologous regions of the brain hemispheres. It is shown that CC has functions such as providing attention and arousal (5) language and auditory interactions, organizing bimanual motor output (6), aiding memory storage and recall (7).

Abnormalities of the CC may not cause any neurological symptoms, on the other hand they may also lead to severe conditions such as mental, motor and speech disorders. Various neurological diseases and syndromes may be associated with abnormalities in the CC. Therefore, radiological anatomy of the CC may contribute to diagnostic evaluation in children with neurological or syndromic diseases.

Although some previous studies were present about the dimensions of corpus callosum in different populations (mainly in adults) but there is not enough research examining the reference sizes of CC in every age group and gender in childhood. The aim of this study was to identify the normal values of the corpus callosum subregions using MRI in healthy Turkish children of all age groups and gender.

SUBJECTS AND METHODS

Among 14 852 cranial MRI performed from 2011–2013 at our centre, 2753 MR images of Turkish children aged 0–18 years were acquired. After reviewing the relevant patient data, three paediatricians excluded those patients MRIs (n = 1947) who had intracranial lesions, a history of neurological diseases (except idiopathic epilepsy), psychiatric diseases, or abnormal MRI findings. Thereafter, the MR images were reviewed by four radiologists and 313 of those were excluded due to additional radiologic abnormalities. Eventually, remaining MR images of 493 children (who had been undergone MRI for idiopathic headache and idiopathic epilepsy) were included in the study.

MR measurements

Four radiologists (SS, VA, EO, SI) were initially trained for the measurements by a radiologist (MK) experienced in cranial MR assessment. Before performing the measurements 20 patients were selected for a pilot study. In the pilot study four radiologists performed all measurements and discuss the differences in measurements. At the beginning, 120 patients, were randomly selected and were evaluated by all radiologists to determine interclass correlation coefficient as an inter-observer reliability measure. Finally, all 493 images were examined by one of four radiologists. The flowchart diagram of the study is given in Fig 1.

Measurements

The thickness of the genu, corpus, isthmus, splenium and antero-posterior (AP) diameter of Corpus callosum was measured in the mid-sagittal 3 D–FSE images. Genu was defined as the anterior one third part, whereas corpus was determined as mid-part of CC. The posterior half of the CC was divided into the isthmus and splenium. The isthmus was determined as the part of the CC with the least thickness in the posterior half. The corpus collosum AP diameter was measured from the most anterior part of genu to the posterior edge of splenium on T1 weighted sagittal images (Fig 2).

MR Acquisitions

All MR examinations were performed with 1.5-T (Symphony; Siemens, Erlangen, Germany) or 3-T MR scanners (Achieva; Philips, The Netherlands) by using a head coil. Patients were imaged in the supine position. Conventional MR examination lasted approximately 25 to 30 minutes for each patient. All measurements were performed on multiplanar reformatted images if 3D T1 sequence (repetition time [TR]/echo time [TE], 8.3/3.8

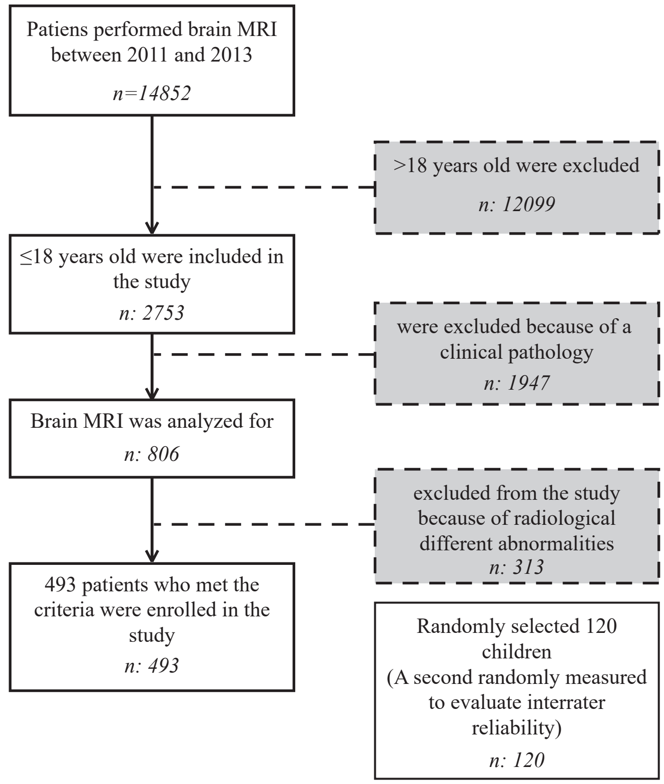

Fig. 1: The flowchart diagram of the study.

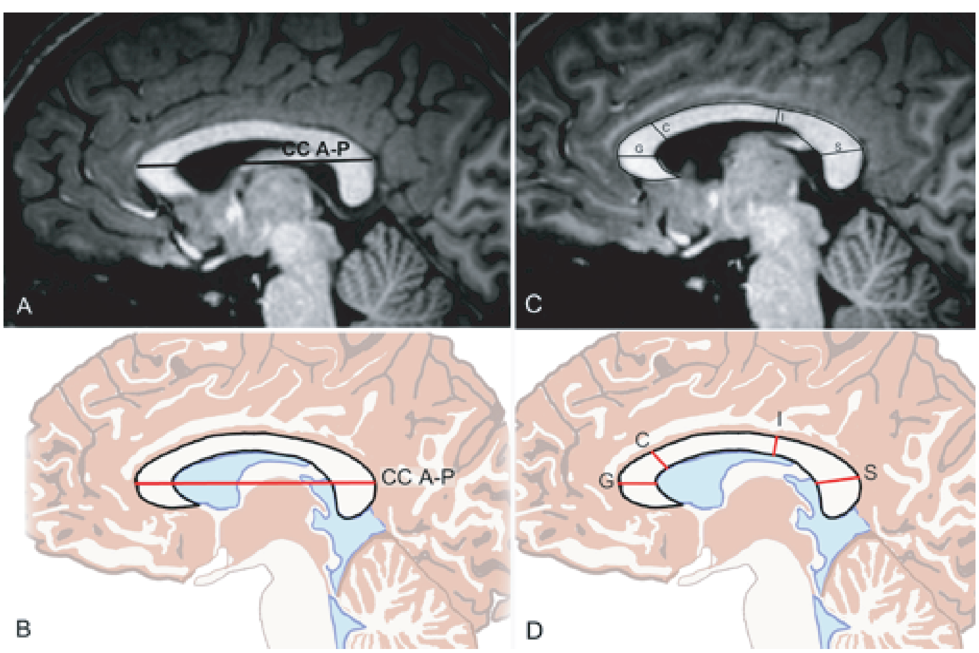

Fig. 2: Measurements of corpus callosum on the mid-sagittal cross sectional image. CC A-P: corpus callosum antero-posterior dimension, G: thickness of genu, C: thickness of corpus, I: thickness of isthmus, S: thickness of splenium.

milliseconds; flip angle, 8 degrees; slice thickness, 1 mm) was performed. In those cases without 3D T1 sequence, the measurements were performed on T1 sagittal (repetition time [TR]/echo time [TE], 700/10 milliseconds; flip angle, 70 degrees; slice thickness, 3 mm), T2 axial (repetition time [TR]/echo time (TE), 3000/80 milliseconds; flip angle, 90 degrees; slice thickness, 3 mm) and coronal SPIR (repetition time [TR]/echo time [TE], 3000/80 milliseconds; flip angle, 90 degrees; slice thickness, 3 mm) images.

Statistical analyses

Before the measurement step, a pilot study was conducted and the inter-rater reliability was evaluated by Inter Class Correlation Coefficients. Researcher informed about ICC of different measurement criteria and a discussion section performed to increase accuracy. The measurements were reported as the 3rd, median, and the 97th on scale of mm. Statistical analyses were performed by SPSS for Windows V.15.0 and results visualized by Microsoft Office Excel programme. Measurements are reported for each age group and gender. Drawn lines smoothed by appropriate curve. Independent samples *t*-test was used to compare the pituitary dimensions between male and female groups. A p-value < 0.05 was considered statistically significant.

RESULTS

In total 493 children (0–18 years) were included in the study, 256 of them were boys. Measurements of CC for every gender and age group were taken on MR images. Due to different findings between girls and boys, the results were given separately by gender. Corpus callosum diameters of 10–22 individuals in each age group from both gender were measured on MRI images.

The measurements are shown in Table 1 for girls and Table 2 for boys. As can be seen from the tables, CC dimensions increased with age. It is observed that the corpus sizes are at the maximum level age 11 years in both girls and boys. On the other hand, the splenium measurements increased proportionally with age.

DISCUSSION

In this study we have reported the MRI data of CC in healthy children of both gender and all age groups under 18 years old.

The anatomical structure and dimensions of CC may provide important clues for various diseases. The anatomical structure of CC in different disease groups have been studied. For example, in a study authors researched the CC dimensions of children with cerebral palsy. They declared that these children had significantly smaller CC surface area than healthy children. They also suggested that if CC gets damaged during the course of development then it is associated with poor neurological outcome and neuropsychological performance (8). However, we found only one study in the literature about the reference data the of CC sub-region dimensions in the paediatric age group (9). So we suggest that reference CC dimensions in different populations according to their age group are required to be identified.

It is known that the shape and size of the CC changes and develops depending on age and gender (3). Therefore, CC sizes should be evaluated separately for each age group. But especially in childhood, where there is a dynamic process, the reference values determined for each age and gender from different populations are not available. Although there are some earlier studies on the basis of MR images about this subject (3, 8–12), there is not enough large scale studies determining standard values for all age groups of children. In this study, we aimed to determine the normal values of CC sub-region dimensions for each age group of children. To know the developmental stages and the dimensions of CC for each age group is important for diagnosis of some clinical features such as cerebral palsy, autism, and mental retardation and especially during some surgical procedures like collasotomy for the treatment of some refractory epilepsies (8, 11). In some earlier studies, it was reported that partial or total agenesis of the corpus callosum may be related to different clinical abnormalities like prematurity, mental retardation, cerebal palsy, autism, infantile spasm and craniosynostosis (8). We have determined that CC sizes increased in parallel with increasing age, as it is expected.

As mentioned in the methods section, the thickness of the genu, corpus, isthmus, splenium and antero-posterior diameter of CC were measured on the MR images. Surface area or volume measurements were performed in different previous studies, but it is a fact that volume and area measurements are non-practical and time consuming methods for daily neuroradiological applications. We aimed in this study to demonstrate data that can be used in daily practice.

Although there were previous studies about the callosal measurements, there is not enough data on CC dimensions for different populations and especially in children (10). Garel *et al* (9) from France studied the reference data of CC biometry in children. They included 624 children from one day to 15 years old. Karakaş

Table 1: Corpus callosum subregions measurements in girls (n = 237)

		Genu (mm)			Corpus (mm)			Isthmus (mm)			Splenium (mm)			CC A-P (mm)		
Age	**n**	**3%**	**Median**	**97%**	**3%**	**Median**	**97%**	**3%**	**Median**	**97%**	**3%**	**Median**	**97%**	**3%**	**Median**	**97%**
0	10	3.9	5.3	6.9	2.4	3.0	4.0	2.4	3.1	4.0	3.9	5.0	7.4	44.0	47.9	53.0
1	15	4.3	7.1	8.8	2.3	3.9	5.8	2.3	3.9	5.8	2.7	6.8	8.3	44.6	52.5	63.0
2	10	5.0	7.9	11.0	3.4	4.5	6.5	3.4	4.5	6.5	6.9	8.1	9.5	50.0	57.7	69.0
3	13	7.0	9.8	11.3	3.0	5.0	7.6	3.0	5.0	7.6	5.7	8.6	11.1	49.0	59.1	64.0
4	12	7.2	8.4	9.9	4.8	5.4	6.5	4.8	5.4	6.5	6.8	8.4	10.0	54.0	57.3	63.0
5	14	7.5	9.4	11.7	3.9	5.0	6.8	3.9	5.0	6.8	6.1	8.7	10.8	53.0	60.9	63.7
6	12	8.8	10.2	13.3	5.6	7.0	8.6	5.6	7.0	8.6	5.7	8.9	13.1	58.0	63.5	72.0
7	14	8.7	10.4	11.7	4.7	5.6	6.0	4.7	5.6	6.0	7.0	9.6	12.1	57.0	62.3	70.5
8	13	7.8	10.0	12.7	4.9	6.0	7.0	4.9	6.0	7.0	8.3	9.7	10.7	58.0	63.0	72.0
9	10	7.8	9.4	12.1	4.1	6.0	7.8	4.1	6.0	7.8	8.1	9.6	10.5	57.5	63.7	77.0
10	10	9.2	10.7	13.0	4.9	7.0	8.7	4.9	7.0	8.7	7.4	9.8	10.7	61.0	66.5	70.4
11	11	7.8	12.0	13.0	5.0	8.1	9.6	5.0	8.1	9.6	6.6	10.0	11.0	55.0	68.0	77.0
12	13	7.6	10.7	12.7	5.0	7.6	9.6	5.0	7.6	9.6	5.7	10.0	11.7	54.0	67.0	70.0
13	21	8.0	10.7	14.8	5.0	6.6	9.6	5.0	6.6	9.6	8.5	10.5	12.1	60.0	66.0	75.0
14	16	9.0	11.0	14.0	4.4	6.6	8.3	4.4	6.6	8.3	9.0	11.0	12.2	61.0	69.8	77.0
15	17	8.8	10.7	13.6	4.8	5.9	6.9	4.8	5.9	6.9	9.7	10.5	12.0	63.0	68.6	77.0
16	18	9.4	11.2	15.0	3.9	6.5	7.7	3.9	6.5	7.7	7.4	10.8	13.1	60.0	70.7	81.7
17	17	8.7	10.9	13.1	4.9	6.5	8.9	4.9	6.5	8.9	8.6	10.8	13.6	62.7	69.9	75.0
18	11	8.3	10.7	13.6	3.5	6.8	9.1	3.5	6.8	9.1	8.2	11.3	12.5	66.0	70.4	75.1

**CC A-P: Corpus callosum antero-posterior dimension*

Table 2: Corpus callosum subregions measurements in boys (n = 236)

		Genu (mm)			Corpus (mm)			Isthmus (mm)			Splenium (mm)			CC A-P (mm)		
Age	**n**	**3%**	**Median**	**97%**	**3%**	**Median**	**97%**	**3%**	**Median**	**97%**	**3%**	**Median**	**97%**	**3%**	**Median**	**97%**
0	13	3.9	6.1	6.8	2.0	3.1	5.2	2.0	3.1	5.2	3.2	4.9	7.8	41.0	47.0	56.0
1	14	4.9	7.5	8.7	3.0	3.8	5.2	3.0	3.8	5.2	4.8	6.7	8.9	47.0	52.5	58.6
2	13	7.5	8.7	10.0	3.9	4.9	6.2	3.9	4.9	6.2	7.0	8.1	10.0	45.0	60.0	72.0
3	11	7.5	9.7	10.3	4.3	5.0	5.9	4.3	5.0	5.9	7.7	8.5	11.7	54.0	61.0	70.0
4	14	5.9	9.4	10.8	4.0	4.9	5.9	4.0	4.9	5.9	6.9	8.7	10.5	53.0	62.4	70.0
5	15	6.9	9.4	12.7	4.0	5.8	8.0	4.0	5.8	8.0	6.7	8.0	9.9	52.0	62.0	70.0
6	10	9.4	10.6	12.0	4.8	6.1	6.9	4.8	6.1	6.9	6.9	8.7	10.8	58.0	63.5	73.0
7	17	7.2	9.6	12.0	4.4	6.1	7.6	4.4	6.1	7.6	7.6	9.6	13.0	54.5	65.9	72.0
8	11	6.0	9.8	12.7	4.7	6.0	8.0	4.7	6.0	8.0	6.7	10.1	11.7	53.0	63.0	66.9
9	12	8.7	10.6	11.7	4.9	7.0	8.7	4.9	7.0	8.7	7.0	8.6	11.8	56.0	61.3	70.0
10	12	7.8	10.9	12.8	5.0	7.3	9.2	5.0	7.3	9.2	9.0	9.9	11.7	63.0	67.5	74.0
11	13	6.6	9.8	13.1	5.5	7.6	8.6	5.5	7.6	8.6	8.8	10.0	11.3	60.0	66.0	72.0
12	15	7.8	9.8	13.6	5.0	7.6	8.4	5.0	7.6	8.4	8.8	10.1	12.0	60.0	67.0	77.0
13	10	7.5	10.0	12.7	3.9	7.0	9.5	3.9	7.0	9.5	8.4	10.6	12.7	63.0	67.8	73.0
14	17	8.4	11.7	13.6	4.9	7.0	9.0	4.9	7.0	9.0	8.9	9.9	14.7	63.0	67.0	76.0
15	14	8.0	10.7	12.8	3.9	5.9	6.9	3.9	5.9	6.9	8.7	10.6	12.4	59.0	68.4	80.0
16	22	7.9	11.3	13.0	4.0	5.9	8.0	4.0	5.9	8.0	7.4	10.7	12.4	61.0	68.9	76.0
17	11	10.6	10.8	12.7	4.9	6.9	9.8	4.9	6.9	9.8	9.0	11.3	13.6	56.0	69.5	76.0
18	12	9.0	11.5	13.0	4.9	6.8	7.8	4.9	6.8	7.8	9.8	11.7	13.0	64.0	70.3	75.0

**CC A-P: Corpus callosum antero-posterior dimension* *et al* (12) from Turkey, investigated the normal dimensions of the sub-regions of CC, examining MR images of 52 healthy adults aged 20–50 years. There is no wide spread study on Turkish children of all ages and gender. As far as we are aware, this is the first study determining CC sub-region measurements in children from newborn to 18 years old.

Cranium and brain sizes are known to be bigger in males than females, so CC sizes are supposed to be larger in size in men. Some studies suggested that CC sizes are not changed according to gender (11, 13–16) However, there are also other studies suggesting that CC sizes are relatively bigger in girls than males (17, 18). Similar to our data, Garel *et al* (9) also observed that there is a faster growth until about age three years in both girls and boys. Sullivan *et al* (19) investigated the dimensions of CC in adults (22–71 years) if it varies by age and gender. They assert that the CC midsagittal surface area is unchanged with age but men had larger surface area in relation to the larger volume of brain than females. In a study, CC dimensions of 104 patients with ages ranging from 19 to 65 years were investigated for sexual dimorphism and the authors suggested that there is no difference between males and females, only the rostral part of the corpus is said to be slightly larger in males (13). Giedd *et al* (3) measured the midsagittal CC sizes of 114 healthy children between the ages of 4–18 years. Gender differences were not detected. The front parts (rostrum and genu) have been suggested to have slower growth rate than the rear sections. In this study, we did not detect a significant difference between girls and boys according to thickness of CC sub-regions and anteroposterior dimension of CC.

In the early years of life, the thickness of the CC increased in accordance with the faster myelin formation, but there may be a slowdown in the growth rate in adolescence due to completion of myelination of neurons. It is reported that CC maturation direction is anterior to posterior, and around the ages of 10–11 years is a critical time that the maturation of posterior CC regions is more pronounced. Especially measurements of the corpus thickness reached at almost the highest values in our study, was found to be consistent with these literature data (4). We also detected in our study that the splenium and CC A-P measurements showed a linear increase with age in both girls and boys. The corpus measurements reached the maximum level at the age of 11 years in both genders. We think that this may be associated with myelination and development of neural fibres in early life and adolescents.

There are some limitations of the present study as follows. Number of cases was not sufficient to generate percentile curves so could not be given as a graph. Although the differences between radiologists are minimized with two pilot studies to determine interclass correlation coefficient as an inter-observer reliability measure, all cases were not evaluated by the same radiologist

CONCLUSION

Corpus callosum is a very important anatomical structure for the transmission of signals between two hemispheres. Even the mild structural disorders of CC may be an important clue in the diagnosis of neurological diseases or syndromes in childhood. At this point, we think that it is important to determine the reference values of CC dimensions in healthy children in order to detect deviation from normal. The present study demonstrated the CC sub-region dimensions of children in

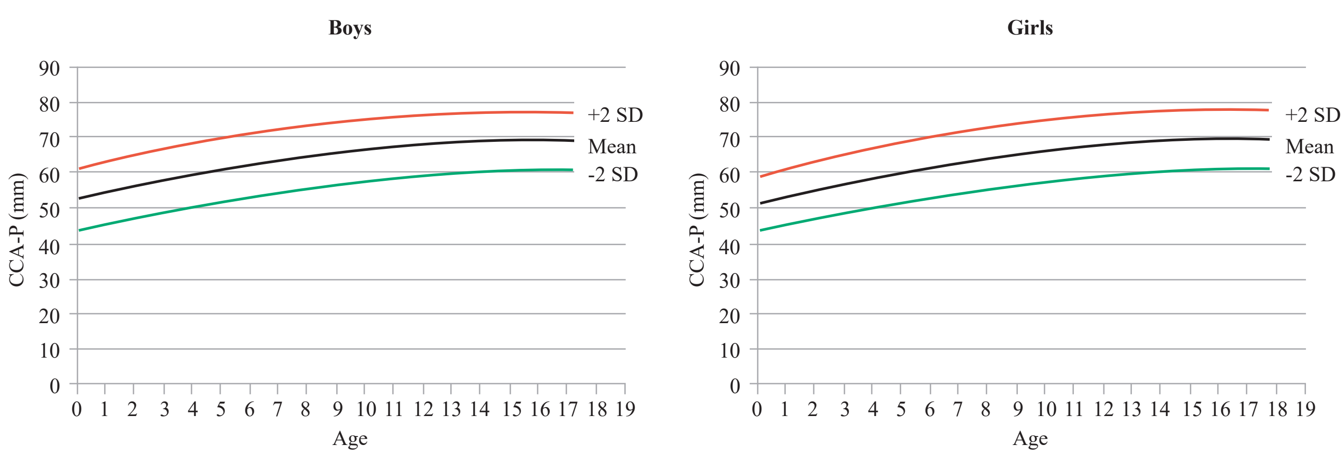

Fig. 3: Corpus callosum antero-posterior dimensions of boys and girls as graphic.

various age groups from newborn to adolescence. Larger scale studies are required to be made on this subject.

Conflict of interest: There are no conflicts of interest.

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