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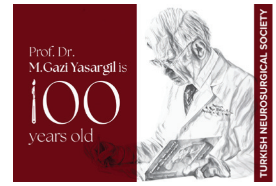

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Correlation of Transfontanel Ultrasonography and Brain Magnetic Resonance Imaging Measurements in Neonates with Hydrocephalus

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ABSTRACT

AIM: To evaluate whether transfontanel ultrasonography could serve as a practical and less complex alternative to brain magnetic resonance imaging in infants with hydrocephalus.

MATERIAL and METHODS: In this prospective study, 54 infants diagnosed with hydrocephalus underwent both transfontanel ultrasonography and brain magnetic resonance imaging. A neonatologist and a radiologist independently assessed ventricular measurements, including the Evans index, frontooccipital horn ratio, bilateral ventricular index, anterior horn width, thalamooccipital distance, callosal angle, and corpus callosum length.

RESULTS: Among the 54 infants, 48 (88.9%) received a ventriculoperitoneal shunt. A strong correlation was found between transfontanel ultrasonography and magnetic resonance imaging for most ventricular measurements: Evans index (r=0.875, p=0.0001), frontooccipital horn ratio (r=0.867, p=0.0001), callosal angle (r=0.868, p=0.0001), bilateral ventricular index (left r=0.937, right r=0.944; p=0.0001 for both), bilateral anterior horn width (left r=0.918, right r=0.908; p=0.0001 for both), and bilateral thalamooccipital distance (left r=0.956, right r=0.919; p=0.0001 for both). The correlation for corpus callosum length was statistically significant but weaker (r=0.386, p=0.004).

CONCLUSION: Our study emphasizes that transfontanel ultrasonography—which achieves better results in experienced hands—should be widespread and an excellent alternative to unnecessary and repeated imaging methods.

KEYWORDS: Hydrocephalus, Magnetic resonance imaging, Transfontanel ultrasonography, Infant, Neuroimaging

ABBREVIATIONS: AHW: Anterior horn width, **CA:** Callosal angle, **CT:** Computed tomography, **EVD:** External ventricular drain, **FOHR:** Frontal occipital horn ratio, **MRI:** Magnetic resonance imaging, **TFUS:** Transfontanel ultrasonography, **TOD:** Thalamooccipital distance, **USG:** Ultrasonography, **VI:** Ventricular index, **VPS:** Ventriculoperitoneal shunt

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INTRODUCTION

Hydrocephalus results from obstruction, impaired absorption, or overproduction of the cerebrospinal fluid pathways due to several developmental, genetic, and inherited abnormalities. It can damage the neurodevelopmental outcome of affected newborns (13,31). Its incidence ranges from 0.3 to 2.5 per 1,000 live births, and it is one of the most common congenital anomalies of the nervous system (13). Hydrocephalus in infants can be congenital or acquired, with congenital forms being either syndromic—involving conditions such as neural tube defects, craniosynostosis, and X-linked inheritance—or nonsyndromic (31).

Measuring ventricular size is essential in pediatric patients with hydrocephalus because the severity of ventricular dilatation is related to an enhanced risk of adverse neurodevelopmental outcomes in fetuses with isolated ventriculomegaly (7). In the diagnosis and treatment of newborns, ultrasonography (USG), computed tomography (CT), or magnetic resonance imaging (MRI) are frequently carried out. Transfontanel ultrasonography (TFUS) is a highly effective, cost-effective, and noninvasive diagnostic tool for rapidly evaluating the anatomy of the infant's brain and detecting normal and abnormal findings in detail (23). It also has limitations in assessing complex malformations, vascular pathologies, and obstetric trauma, detecting small parenchymal pathologies and cerebral infarction, and evaluating white matter injury. TFUS enables evaluating supratentorial structures in more detail, whereas the evaluation of infratentorial structures is relatively restricted (11). Definitions have been determined according to the measurements of the ventricles (3), and studies comparing MRI/CT with USG measurements are minimal.

With the development of technology and the diversification of imaging methods for hydrocephalus and ventriculomegaly, diagnosis and post-treatment follow-up can be performed with a large number of linear measurements. Reference values for ventricular index (VI), anterior horn width (AHW), and thalamooccipital distance (TOD) have been established for neonatal lateral ventricles, which might enable the early identification of posthemorrhagic ventricular dilatation and the accurate timing of interventions in infants with ventricular dilatation (3). USG-derived frontal occipital horn (FOHR) and frontal temporal horn are reliable indices for clinically monitoring infantile ventriculomegaly in infants younger than six months (25). It is a valuable tool for following pediatric hydrocephalus patients (24). In the last decade, studies have shown that callosal angle (CA) measurement correlates with the Evans index, which has been used for years in the diagnosis of ventriculomegaly and hydrocephalus in both adult and pediatric patients (17,32). With the expansion of the lateral ventricles, the corpus callosum primarily exhibits elevation of its body and—to a lesser extent—an increase in length (15).

This study aims to compare linear USG with MRI measurements in hydrocephalus because USG can be used at the bedside and has no radiation risk. Moreover, it seeks to ascertain whether USG can be utilized as a more straightforward imaging method in hydrocephalic infants.

MATERIAL and METHODS

Participants

This study was conducted in line with the principles of the Declaration of Helsinki. After obtaining approval from the Yuzuncu Yil University Clinical Research Ethics Committee (Decision no: 15/11/2023-05), 60 newborn infants with hydrocephalus who were admitted to the neonatal intensive care unit of our hospital in 2023–2024 were included in the study. Demographic features (sex, gestational age, birth weight, type of delivery, consanguineous marriage, maternal age, and type of surgery required for hydrocephalus) and additional anomalies were recorded. Patients with hydrocephalus whose measurements could not be performed due to massive hydrocephalus were excluded. The legal parents of the patients were informed about the study. Informed consent was obtained from all individual participants enrolled in the study.

Measurements

Evans index, FOHR, bilateral TOD, bilateral AHW, bilateral ventricular index, CA, and corpus callosum length measurements were performed on the same day by a radiologist experienced in brain MR imaging recommended by neurosurgical consultation, and by a neonatologist with TFUS.

The Evans index is the ratio of the frontal horns' maximum width to the skull's maximum internal diameter.

FOHR is determined by adding the largest diameter of the frontal and occipital horns and dividing by twice the biparietal diameter.

VI is the distance between the most lateral side of the ventricles and the interhemispheric fissure in the coronal section, showing the third ventricle.

AHW is the widest distance between the ventricular walls in the coronal section through the third ventricle.

TOD is measured between the farthest posterior points of the thalamus and the lateral ventricle in the sagittal section, where the lateral ventricle is seen in its entirety. Ventricular index, anterior horn, and thalamo-occipital distance were measured independently for the right and left.

CA was measured on coronal sections at the point where the vertical line descending from the anterior commissure and posterior commissure planes—90° from the posterior commissure line—crossed the lateral ventricles.

Corpus callosum length measurements were performed on the best midsagittal sections from the most anterior to the most posterior view. Figure 1 shows representative TFUS and cranial MRI measurements.

Image Analysis

A senior neonatologist with fifteen years of experience conducted cranial ultrasound measurements with a bedside ultrasound device (Mindray, Diagnostic Ultrasound System, DC-N3 PRO, 2022). Standard coronal and sagittal section images were collected through the anterior fontanelle. For MRI protocol, a Siemens Altea 1.5 tesla MR was used to obtain

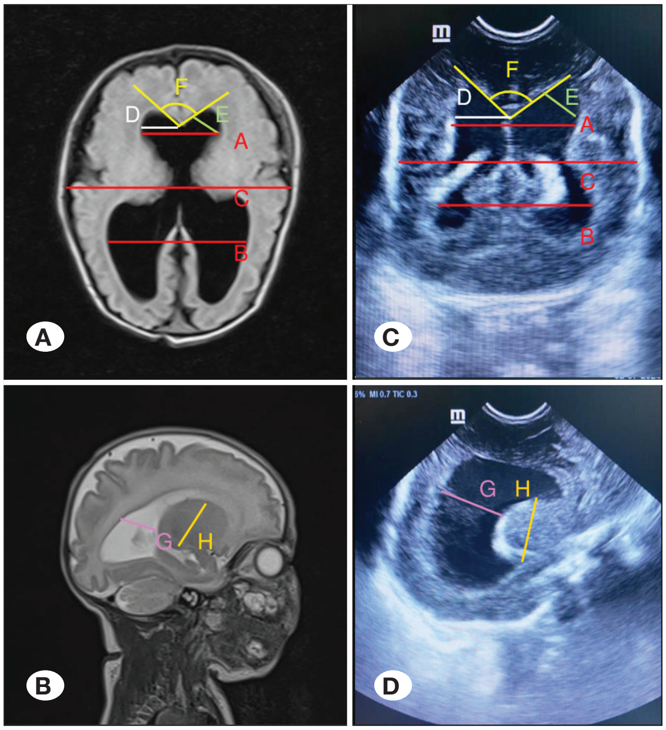

Figure 1: Representative images for MRI **(A,B)** and TFUS **(C,D)** measurements. Evans index=A/B; FOHR=A+B/2C; bilateral ventricular index=D; bilateral anterior horn width=E; callosal angle=F; bilateral thalamooccipital distance=G; corpus callosum length=H.

two-dimensional T1AG, T2AG and flair sequences with 5×5 cm contiguous axial and sagittal scans, and 3 mm sections were obtained. The sonogram neonatologist and senior radiologist for the MRI scans were blinded to infant history and previous radiology reports, and both methods were measured on the same postnatal day.

Statistical Analysis

Descriptive statistics for continuous variables are expressed as the mean, standard error, minimum, and maximum values, while descriptive statistics for categorical variables are expressed as numbers and percentages. The independent t-test was used to compare continuous variables according to categorical variables. Pearson correlation coefficients were calculated to evaluate the relationships between continuous variables. For Pearson correlation coefficients, values greater than 0.4 and up to 0.69 were classified as low correlations, those between 0.7 and 0.89 were considered moderate, and coefficients exceeding 0.9 were interpreted as indicating strong to very strong correlations (28). The statistical significance level was set at 0.05, and SPSS (version: 26) statistical package software was utilized for calculations.

RESULTS

Sixty newborns with hydrocephalus were hospitalized in our hospital unit during the study period. Six patients whose radiologic measurements could not be performed due to massive hydranencephaly were excluded from the study. Therefore, ultimately the researchers could measure 54 newborns with hydrocephalus. Table I provides demographic characteristics of the hydrocephalic newborns included in the study.

No statistically significant difference was found between the measurements in binary comparisons (Table II). After comparing the correlations of brain MRI and TFUS measurements, Evans index (r=0.875, p=0.0001), FOHR (r=0.867, p=0.0001), CA (r=0.868, p=0.0001), bilateral VI (left r=0.937, p=0.0001; right r=0.944, p=0.0001), bilateral AHW (left r=0.918, p=0.0001; right r=0.908, p=0.0001), and bilateral TOD (left r=0.956, p=0.0001; right r=0.919, p=0.0001) were found to be significantly correlated. Although the corpus callosum length was statistically significant between different imaging modalities, the correlation between the analyses was not as strong as the other measurements (r=0.386, p=0.004; Figure 2).

DISCUSSION

Transfontanelle ultrasonography is a valuable tool for detecting intracranial lesions in infants. Hydrocephalus is the most common indication for performing the scan, as well as the most frequently observed abnormality (12).

In the literature, there are many studies on TFUS, including a large number of cases. However, there are few studies for newborns in which many cranial parameters are measured and MR-CT measurements are compared. In the study of neonatal neuroanatomy and disease, TFUS—which is widely used—offers many advantages, including the lack of ionizing radiation and its portability, wide availability, and low cost (21), and it might also provide volumetric measurements (1). The potential disadvantages of the technique are that it is operator-centered and requires a suitable acoustic window (11). MRI has become widespread as a promising imaging tool since 2007, especially for the central nervous system (22). In method comparison research, studies comparing USG with MRI (10,25)—which is often not available in every center and requires sedation—and CT—which carries radiation risk—have been conducted in many diseases (16,24).

Transfontanelle ultrasonography (TFUS) was used to detect intraventricular hemorrhage in preterm neonates by scanning through the anterior fontanel in both coronal and sagittal sections at multiple time points within the first two weeks of life. The findings were classified based on severity, and TFUS is the imaging modality used for early detection and grading of intraventricular hemorrhage in preterm neonates (8). Cross-sectional and longitudinal reference curves were generated for VI, AHW, and TOD according to USG measurements for early definition and measurement of ventriculomegaly due to either posthemorrhagic ventricular dilation or loss of periventricular white matter (3). AHW is a linear measurement in a single plane that is easy to measure and consistent for ventriculomegaly with a reliable cut-off value of 6 mm, independent of postmenstrual age (20). Likewise, although there are curves for AHW as defined by (5), moderate ventricular dilatation should be considered above 6 mm and severe ventricu-

Table I: Demographic Characteristics of Hydrocephalic Newborns

Variables (n=54)		Mean ± Standard Error	Minimum - Maximum
Gestational age (week)		37.48 ± 0.34	(27-40)
Birth weight (grams)		2985.83 ± 99.2	(900-4835)
Maternal age (years)		26.15 ± 1.03	(18-44)
		n (%)	
Sex	Male	29 (53.7)	
	Female	25 (46.3)	
Type of delivery	Caesarian Section	43 (80)	
	Natural Delivery	11 (20)	
Surgery for hydrocephalus	VPS	48 (88.9)	
	EVD	3 (5.6)	
	None	3 (5.6)	
Neural tube defect		48 (88.9)	
Consanguineous marriage		12 (22.2)	
Mortality		3 (5.5)	

***VPS:** Ventriculoperitoneal shunt, **EVD:** External ventricular drain.*

Table II: Comparison of Measurements with TFUS and Cranial MRI (Mean ± Standart Error)

Measurements	TFUS	MRI	t-test	p-value
Evans index	0.43 ± 0.007	0.42 ± 0.008	0.981	0.329
Frontooccipital horn ratio	0.48 ± 0.01	0.48 ± 0.01	-0.087	0.931
Ventricular index- L (mm)	16.77 ± 0.8	16.14 ± 0.74	0.57	0.56
Ventricular index- R (mm)	16.11 ± 0.72	16.95 ± 0.81	-0.77	0.44
Anterior horn width- L (mm)	13.45 ± 0.64	13.63 ± 0.68	-0.185	0.85
Anterior horn width- R (mm)	13.23 ± 0.7	13.29 ± 0.73	-0.058	0.95
Thalamooccipital distance- L (mm)	36.23 ± 1.0	37.54 ± 0.99	-0.925	0.35
Thalamooccipital distance- R (mm)	37.81 ± 1.2	38.18 ± 1.3	-0.205	0.83
Corpus callosum length (mm)	45.09 ± 0.66	44.28 ± 0.71	0.83	0.406
Callosal angle (°)	81.45 ± 2.03	80.77 ± 1.7	0.256	0.79

***TFUS:** Transfontanel ultrasonography, **MRI:** Magnetic resonance imaging.*

lar dilatation above 10 mm (6). Similarly, while curves exist for TOD, approximately 25 mm is generally accepted as the upper standard limit (5). Treatment approaches for posthemorrhagic hydrocephalus according to baby age in weeks have recently been reported as protocols based on these measurements. The fact that these VI, AHW, and TOD measurements can be measured with both MRI and TFUS shows the importance of USG in the treatment approach and follow-up of the patient over the weeks (9). Left-right ventricular asymmetry was noted both at birth and at term-equivalent age. The absolute differences from side to side exceeded 3 mm for VI and AHW and 7 mm for TOD. Male newborns had a moderately larger ventricle size than female newborns (3). AHW is a reliable ultrasound measure of ventricular enlargement that strongly correlates with intracranial pressure measured noninvasively. This combined assessment can help in managing elevated intracranial pressure in preterm infants with posthemorrhagic hydrocephalus by guiding cerebrospinal fluid removal interventions (2).

It has been reported that shunting decisions can be made with curves created using VI, AHW, and FOHR (20). A recent study has shown that while AHW and VI only provide information

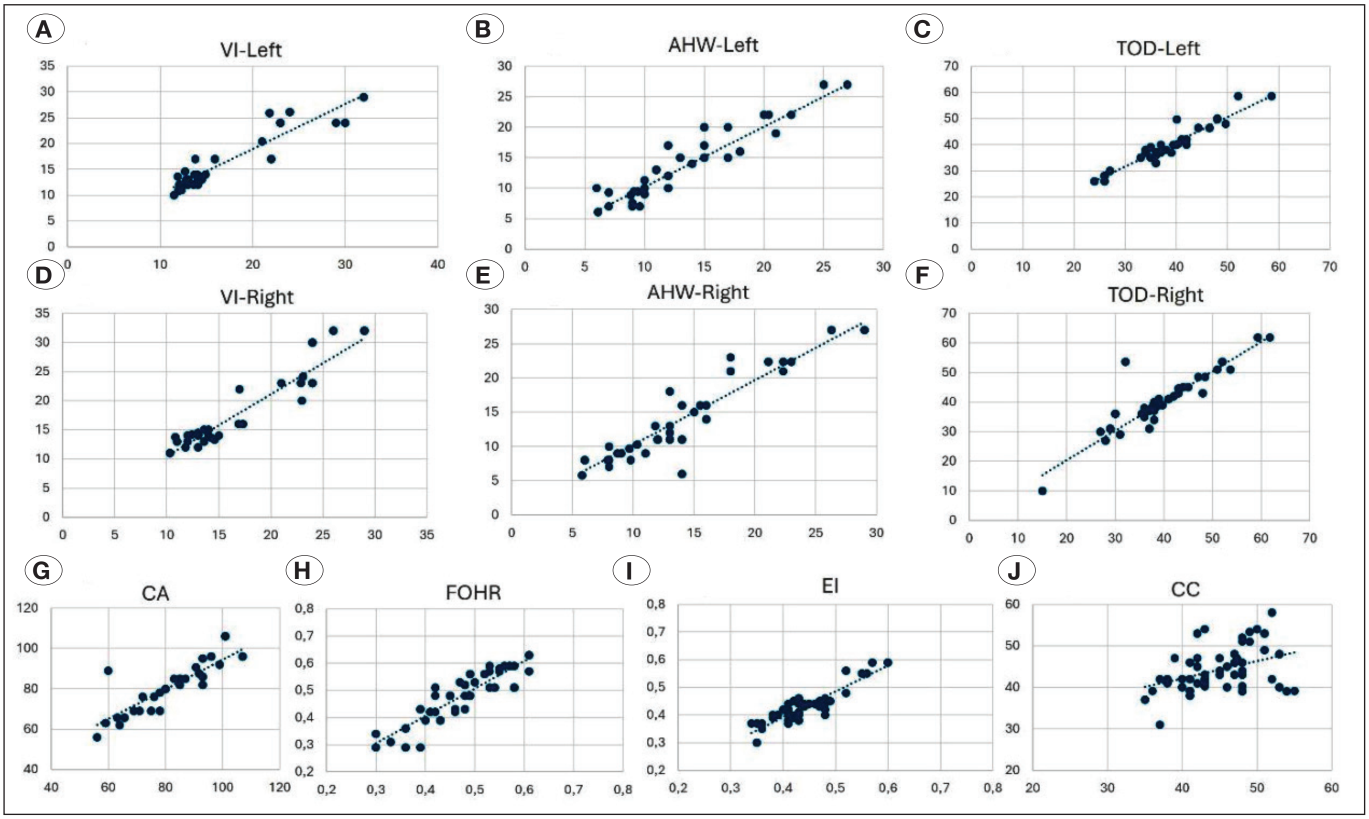

Figure 2: Correlations of TFUS and brain MRI measurements in hydrocephalic neonates. **A, D)** Bilateral ventricular index (left r=0.937, p=0.0001; right r=0.944, p=0. 0001); **B, E)** Bilateral anterior horn width (left r=0.918, p=0.0001; right r=0.908, p=0.0001); **C, F)** Bilateral thalamooccipital distance (left r=0.956, p=0.0001; right r=0.919, p=0.0001); **G)** Callosal angle (r=0.868, p=0.0001); **H)** FOHR (r=0.867, p=0.0001); **I)** Evans index (r=0.875, p=0.0001); **J)** Corpus callosum length (r=0.386, p=0.004).

about the anterior structures, FOHR enables evaluating both posterior and anterior structures together (19). FOHR was also measured on CT, MRI, and US scans in 44 normal children, including premature children aged 0–17 years, and the effect of age was evaluated by linear regression. A close correlation has been found between ventricular/brain area ratio and ventricular volume, as well as between ventricular volume and FOHR (24). The high sensitivity (100%) of TFUS in differentiating ventriculomegaly with the FOHR clinical threshold of 0.55 is one of the most prominent findings of the current study. A strong correlation has also been observed between the mean FOHR obtained from US and the mean FOHR obtained from MRI (25). It has been reported that ventricle/brain volume ratios are categorized into mild and severe hydrocephalus stages based on FOHR by volumetric MRI examinations (14). In a study among children compared with a matched age-matched control group, although the Evans index, Frontal horn index, and Bicaudate index also had statistically significant associations with ventricle size indices, FOHR recorded the most significant association with actual ventricle size (26). Infants with adverse composite outcomes had higher FOHR, and increased ventricular volumes were linked to lower Bayley cognitive and motor scores, regardless of group assignment (4).

A study involving 517 children aged 0–18 years and retrospective cranial MRI scans measured third and fourth ventricular widths and the Evans index, which has held diagnostic importance for years. The Evans index was <0.3 and demonstrated a minimal age-related decline. Normative data on ventricles in childhood could be helpful for early diagnosis of hydrocephalus or follow-up of shunt treatment. As data for both sexes and all age groups has been provided, it offers excellent advantages for objective evaluations (27). In a recent study evaluating the clinical value of classification in treating children with suprasellar arachnoid cysts, MRI/CT with Evans index and FOHR measurements were used to assess hydrocephalus follow-up after surgery (34).

In adult patients with hydrocephalus, it was found that surgical treatment and postoperative follow-up in patients with idiopathic normal pressure hydrocephalus can be determined with CA and Evans index measurements, which are preferred in cranial MRI imaging because they can be performed quickly without the need for a radiologist (17). The callosal angle—which has both diagnostic and prognostic value and has recently been frequently used in patients with normal pressure hydrocephalus—significantly increased after endoscopic third ventriculostomy in patients with childhood hydrocephalus on MRI. In the same study, the Evans index, FOHR, and lateral ventricular horn width decreased after successful surgery (30). However, pre-operative radiological markers did not correlate with the response to shunt treatment (18). To our knowledge, no study in the literature has monitored hydrocephalus by CA measurements with TFUS.

In patients with hydrocephalus, alterations in the corpus callosum might take place with or without shunting. Elevation of the corpus callosum by enlarged ventricles can cause the falx cerebri to strike the middle and posterior third of the corpus callosum in the midline, causing notch-like deformities (29). The mechanism is considered mechanical ischemia, and an animal model has demonstrated a reduction in capillary number (33). One study observed that with enlargement of the lateral ventricles, the corpus callosum is elevated mainly in its body and—to a lesser degree—in length. It also suggests that the corpus callosum might resist the deterioration in hydrocephalus to some extent, due to its plasticity (15).

The position of the head might cause differences between the ventricles. On the other hand, it is necessary to visualize some critical anatomical structures to perform the planned measurements. Measurements could not be performed for cases with hydranencephaly, where these structures could not be seen.

CONCLUSION

In infants with hydrocephalus and anterior fontanelle patency, various measurements performed with TFUS by experienced physicians are highly effective. For neurosurgeons, among radiologic examinations for ventriculoperitoneal shunt indication, TFUS has considerable advantages over cranial CT and MRI given that it has no radiation risk. Moreover, it can be performed at the bedside effectively and rapidly. The radiation risk and cost of CT—which are particularly important in children—the fact that MRI cannot be performed in every center, the need for sedation and intubation for MRI in the neonatal period, and its cost make TFUS more critical. Our study emphasizes that TFUS—which achieves better results in experienced hands—should be widespread and an excellent alternative to unnecessary and repeated imaging methods.

Declarations

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Availability of data and materials: The datasets generated and/or analyzed during the current study are available from the corresponding author by reasonable request.

Disclosure: The authors declare no competing interests.

AUTHORSHIP CONTRIBUTION

Study conception and design: NA, OT, HA

Data collection: NA, HA, OT

Analysis and interpretation of results: SK, AAt, AAy, NA

Draft manuscript preparation: NA, AAt

Critical revision of the article: OT, HA

Other (study supervision, fundings, materials, etc...): MB, EY

All authors (NA, HA, EY, MB, AAt, SK, OT, AAy) reviewed the results and approved the final version of the manuscript.

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