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Adoleescent Brain Changes Associated With Drug Use:A Longitudinal Neuroimaging And Urine Analysis Study

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ABSTRACT

Background
Adolescence is a critical period of neurodevelopment characterized by synaptic pruning, myelination, and refinement of neural circuits involved in cognition, executive functioning, and emotional regulation. Exposure to psychoactive substances during this developmental stage may produce measurable structural and functional brain alterations.

Objective
To evaluate neuroanatomical changes associated with cannabinoid and opiate exposure among adolescents using magnetic resonance imaging (MRI) and urine drug analysis.

Methods
A longitudinal observational study was conducted among adolescents aged 15–25 years recruited from private drug rehabilitation cantersofkarachi. Participants underwent structural MRI and diffusion tensor imaging (DTI) assessment. Urine drug screening

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was performed to confirm cannabinoid and opiate exposure. Cortical thickness, hippocampal volume, amygdala morphology, cerebellar volume, and fractional anisotropy (FA) values of the corpus callosum were analysed. Data were statistically analysed using SPSS version 26.

Results

Adolescents with positive urine drug screens demonstrated significantly reduced prefrontal cortical thickness and lower hippocampal volume compared with controls. DTI analysis revealed reduced FA values in the corpus callosum among substance users, suggesting impaired white matter integrity. Structural abnormalities were more pronounced among participants with prolonged substance exposure.

Conclusion

Cannabinoid and opiate exposure during adolescence is associated with measurable neurodevelopmental abnormalities detectable on MRI and DTI. Integration of neuroimaging findings with biochemical confirmation strengthens evidence regarding the neurological impact of adolescent substance use.

Keywords—Adolescence, cannabinoids, opiates, MRI, diffusion tensor imaging, cortical thickness, white matter integrity, urine drug screening.

Introduction

Adolescence represents a vulnerable developmental period characterized by extensive neuronal remodeling, synaptic pruning, and maturation of fronto-limbic neural pathways. During this phase, the brain demonstrates increased neuroplasticity and sensitivity to environmental influences, including psychoactive substances.

Cannabinoids and opiates are among the most commonly misused substances in adolescents. Δ9-tetrahydrocannabinol (THC), the principal psychoactive component of cannabis, acts primarily through cannabinoid receptor type 1 (CB1) pathways and may interfere with synaptic maturation and neurotransmitter regulation. Similarly, opiates may alter neuronal signalling and impair neurodevelopmental processes.

Advances in neuroimaging techniques such as structural magnetic resonance imaging (MRI), diffusion tensor imaging (DTI), and functional MRI (fMRI) have enabled assessment of substance-related structural and functional abnormalities in the adolescent brain. Previous studies suggest that adolescent substance use is associated with reduced cortical thickness, altered hippocampal and amygdala volumes, and disruption of white matter integrity.

Despite increasing evidence, limited longitudinal studies have integrated neuroimaging findings with objective biochemical confirmation of substance exposure. Therefore, this study aimed to evaluate structural brain changes associated with cannabinoid and opiate exposure in adolescents using MRI findings correlated with urine drug analysis.

Materials and Methods

Study Design

A longitudinal observational study was conducted over a period of 12 months.

Study Setting

The study was conducted at the private drug rehabilitation canters of karachi.

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Study Population

Adolescents aged 15–25 years were included in the study.

Inclusion Criteria

Adolescents aged 15–25years, Participants willing to undergo MRI and urine testing.

Confirmed cannabinoid or opiate exposure based on urine drug screening.

Exclusion Criteria

History of major neurological disorders, Congenital brain abnormalities, Severe psychiatric illness unrelated to substance use, Contraindications to MRI.

Sample Size: A total of 100 participants were included. 50 adolescents with confirmed substance exposure.50 age- and sex-matched healthy controls.

Sampling Technique: Non-probability consecutive sampling was used.

Data Collection Procedure

After obtaining informed consent from participants and guardians, demographic and clinical information was recorded using a structured questionnaire.Urine samples were collected and analyzed using immunoassay-based screening tests for cannabinoids and opiates.

MRI and DTI scans were performed using a 3-Tesla MRI scanner. Structural MRI was used to assess cortical thickness and regional brain volumes, while DTI was used to evaluate white matter integrity using fractional anisotropy (FA).

The following regions were analyzed:

Prefrontal cortex, Hippocampus,Amygdala,Corpus callosum, Cerebellum

Outcome Measures: Primary outcome measures included:

Cortical thickness, Hippocampal volume, Amygdala morphology , Fractional anisotropy (FA), Cerebellar volume

Statistical Analysis

Data were analyzed using SPSS version 26. Quantitative variables were expressed as mean ± standard deviation, while qualitative variables were presented as frequencies and percentages. Independent t-tests were used to compare neuroimaging findings between groups. Pearson correlation analysis was performed to evaluate the relationship between duration of substance exposure and MRI abnormalities. A p-value <0.05 was considered statistically significant.

Results

Demographic Characteristics

Among the 100 participants, the mean age was 16.8 ± 1.7 years. Males constituted the majority of substance users.

Table 1: Demographic and Substance Exposure Data

Variable	Substance Users (n=50)	Controls (n=50)
Mean age (years)	16.9 ± 1.8	16.7 ± 1.5
Male gender	68%	64%
Cannabis exposure	72%	0%
Opiate exposure	28%	0%

Table 2: MRI Findings

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Brain Region	MRI Finding	p-value
Prefrontal cortex	Reduced cortical thickness	<0.01
Hippocampus	Reduced volume	<0.05
Amygdala	Variable volume changes	0.08
Corpus callosum	Reduced FA	<0.01
Cerebellum	Mild volume reduction	<0.05

Diffusion Tensor Imaging Findings

DTI analysis revealed lower fractional anisotropy values among substance users, indicating impaired white matter integrity.

Correlation Between Substance Exposure and MRI Findings

Longer duration of substance use was associated with greater reductions in cortical thickness and FA values.

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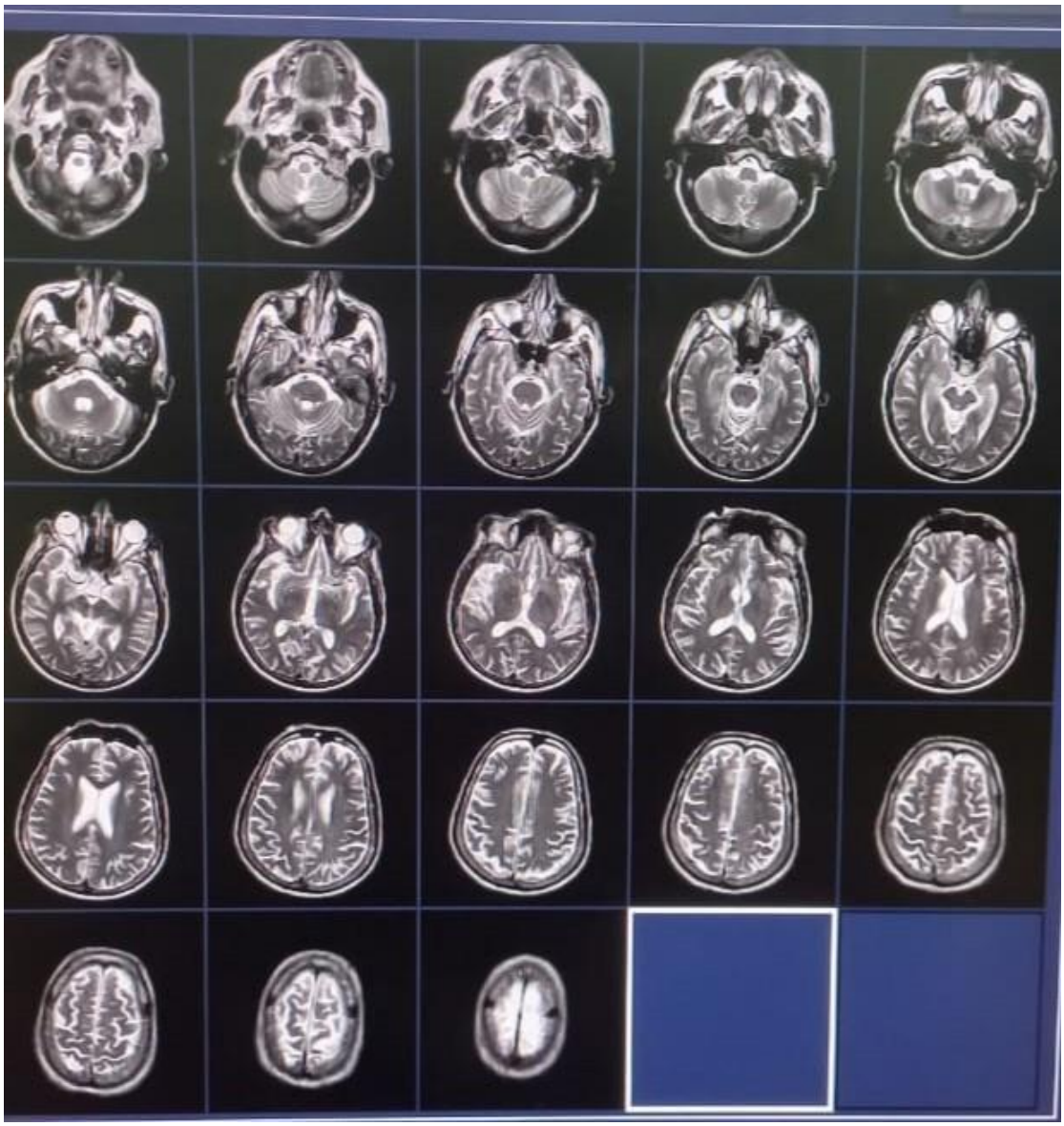

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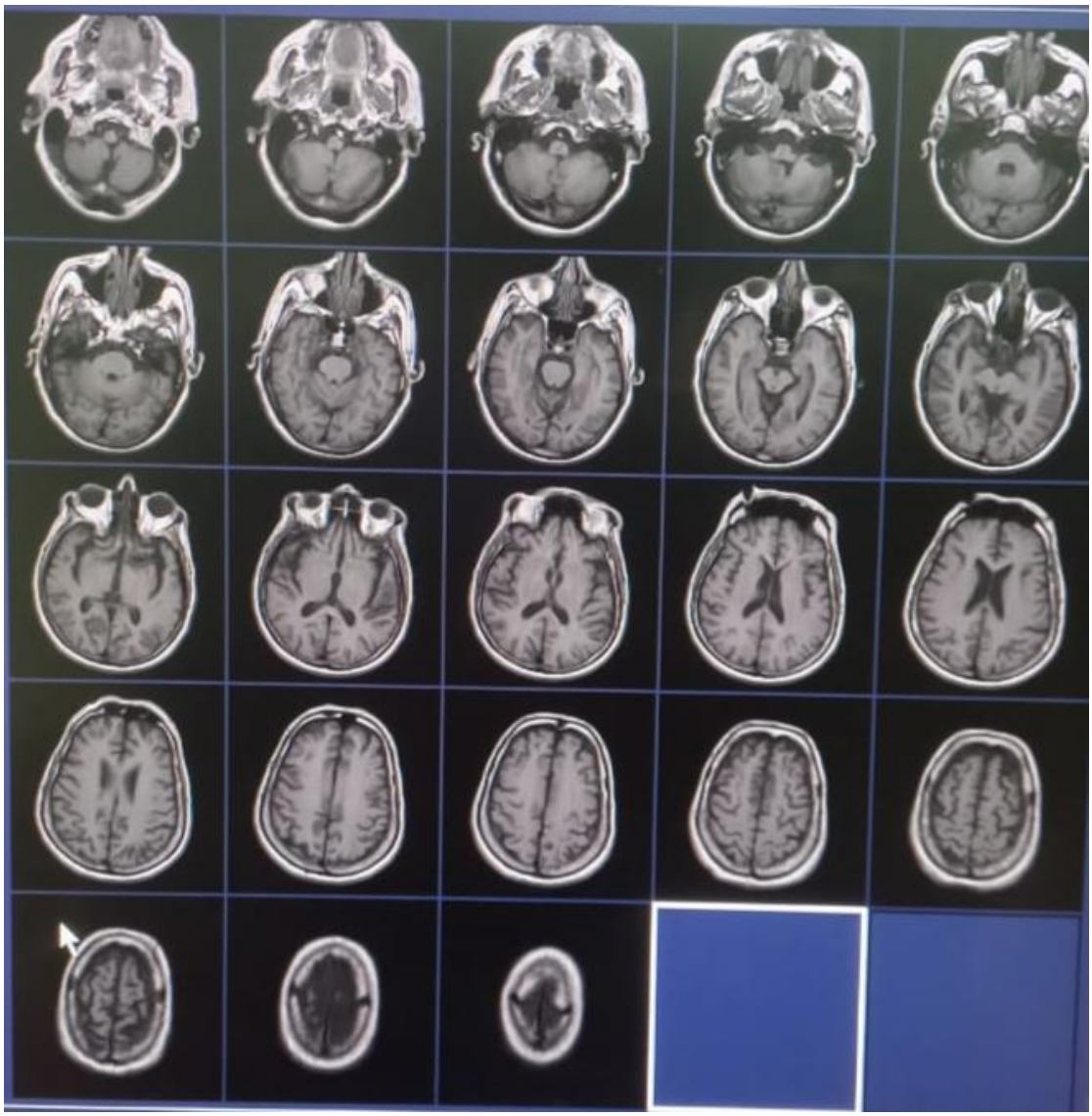

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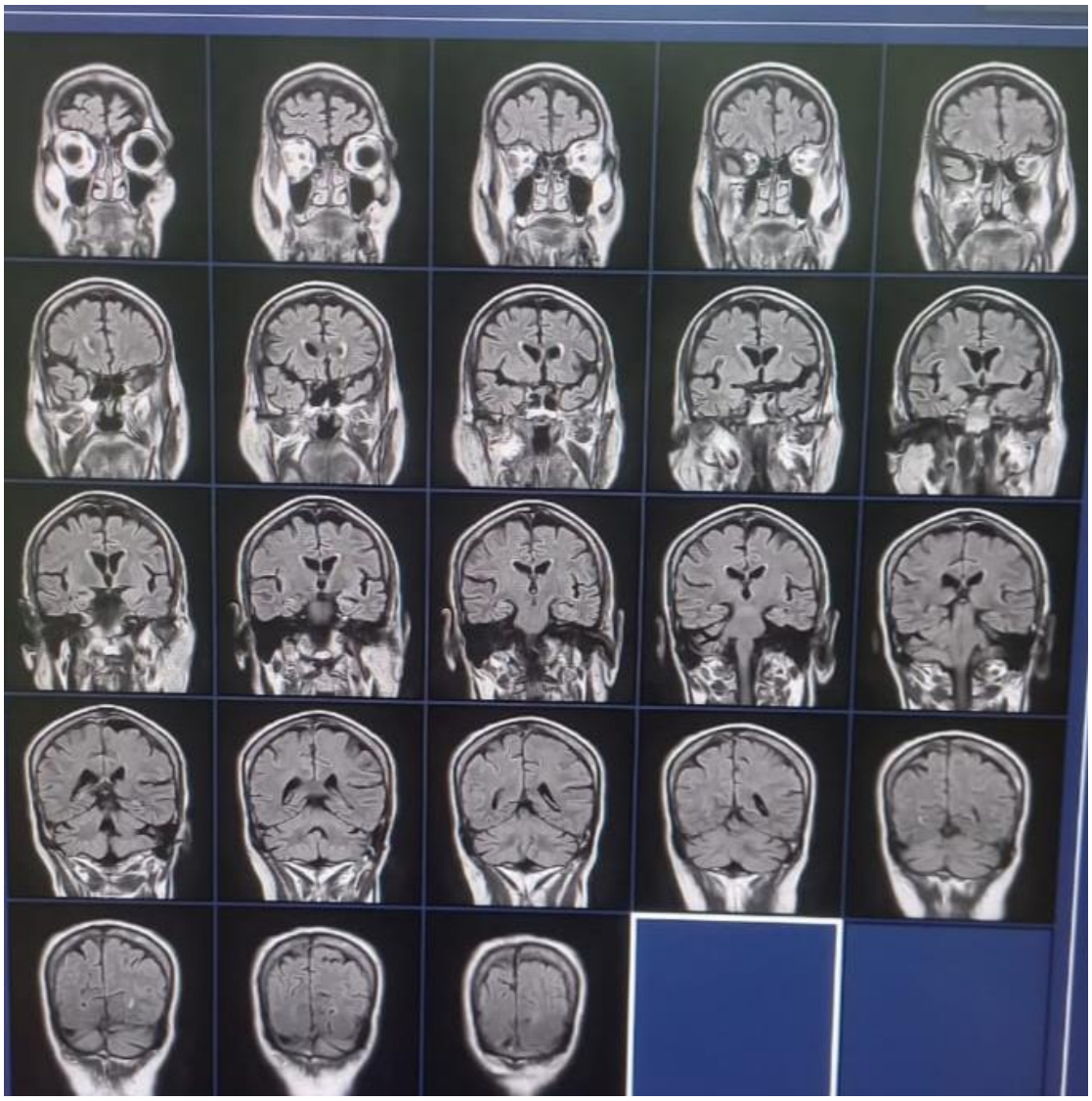

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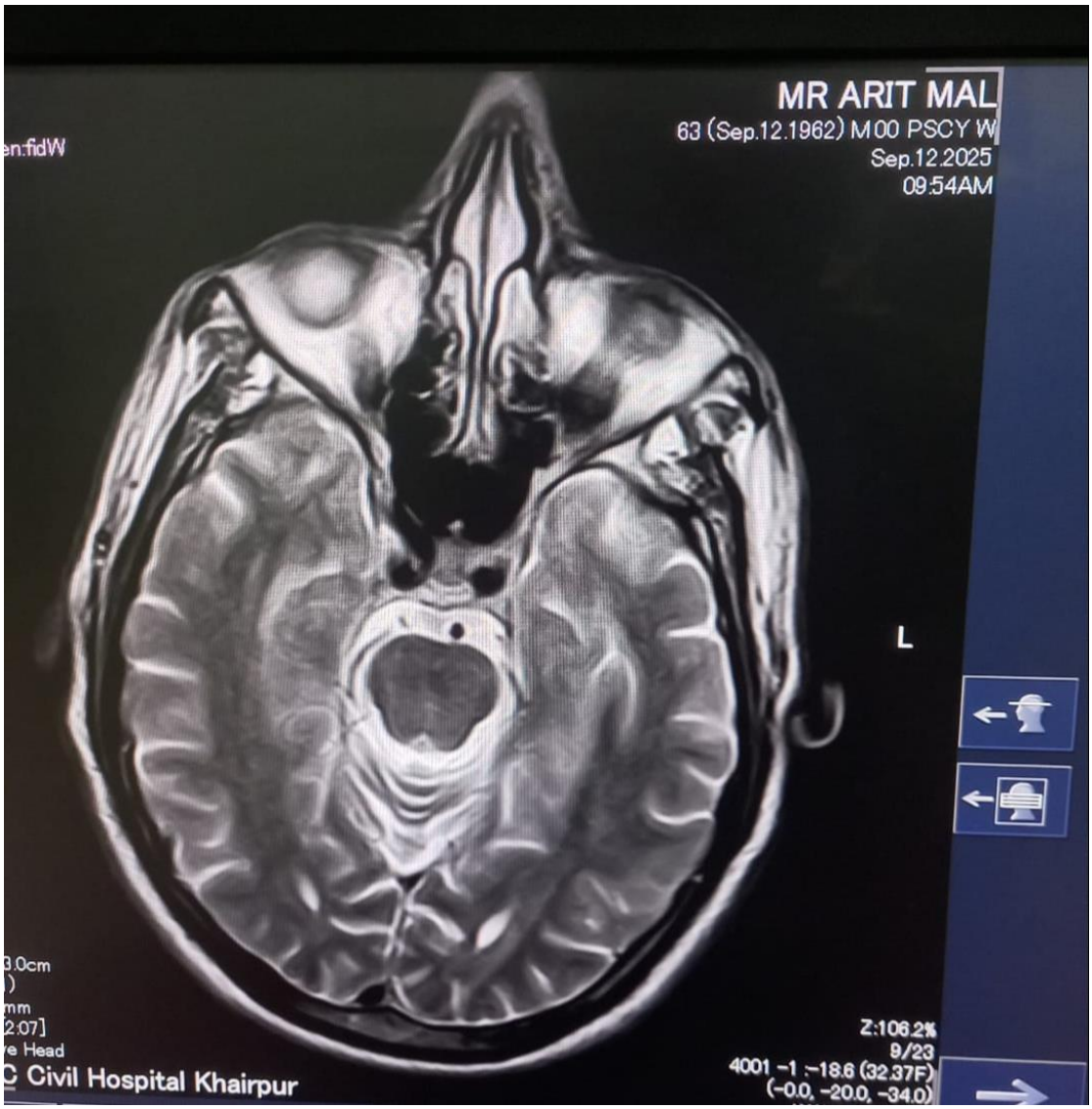

Discussion

The present study demonstrated significant neuroanatomical alterations among adolescents exposed to cannabinoids and opiates. Structural MRI findings revealed reduced cortical thickness in the prefrontal cortex and decreased hippocampal volume among substance users.

The prefrontal cortex is responsible for executive functioning, decision-making, and impulse control. Accelerated cortical thinning observed among substance users may reflect disruption of normal synaptic pruning and neurodevelopmental maturation.

Similarly, reduced hippocampal volume may contribute to impaired learning and memory performance observed in adolescent substance users. DTI findings further demonstrated reduced white matter integrity within the corpus callosum, supporting previous evidence of disrupted interhemispheric connectivity.

The correlation between urine-confirmed substance exposure and neuroimaging

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abnormalities strengthens the validity of the findings and reduces dependence on self-reported drug use.

These findings are consistent with previous neuroimaging studies reporting structural brain abnormalities associated with adolescent cannabis and opiate exposure.

Limitations: Several limitations should be considered. The sample size was relatively small, and polysubstance use may have influenced neuroimaging findings. Additionally, the observational design limits causal inference.

Future studies should include larger multicenter cohorts and long-term follow-up to evaluate recovery trajectories after abstinence.

Conclusion

Adolescent exposure to cannabinoids and opiates is associated with measurable neurodevelopmental abnormalities detectable through MRI and DTI. Reduced cortical thickness, hippocampal atrophy, and impaired white matter integrity were observed among substance users.

Integration of neuroimaging findings with biochemical confirmation through urine drug screening provides stronger evidence regarding the neurological impact of adolescent substance exposure. Early identification and prevention strategies are essential to reduce long-term cognitive and psychiatric complications.

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