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Alterations in white matter integrity in Egyptian youth with smartphone dependence: does DTI have a role?

Alaa Mohamed Reda[1*], Ahmed Elsharkawy[1], Mostafa Mamdouh Kamel[2] and Sara Essam Hasby[1]

Abstract

Background Smartphones provide various functions that facilitate our communication, organization, and entertainment in different situations. Diffusion tensor imaging (DTI) is a method measuring tissue microstructure as well as white matter integrity of the brain and detecting early changes. Several research studies recently aim to utilize conventional MRI for assessing brain structural alterations among smartphone users, *but our study was aimed* at identifying the DTI value while assessing white matter alterations in Egyptian youth with smartphone dependence.

Results Our prospective case–control study involved fifty-three individuals with smart phone dependence (SPD group) as well as twenty-five volunteers who represented the control group. SPD individuals and controls were right-handed. The SPD group mean age exhibited 20.54 ± 1.56 years, while controls exhibited 26.8 ± 15.1 years. When utilizing smart phone addiction scale-short version, SPD group median total score exhibited 33. The diagnostic performance of fornix (fractional anisotropy) FA and external capsule fractional anisotropy (EC FA) regarding area under curve (AUC) exhibited significant increase as opposed to all other tested regions, with a sensitivity of 90.6% as well as a specificity of 96%. While regarding the mean diffusivity (MD), the greatest (AUC) was for EC (0.927, $p < 0.001$), in which the MD value = 0.825 was the cutoff value and able to diagnose the smart phone dependency with a sensitivity of 92.5% as well as a specificity of 76%.

Conclusions Quantitative DTI parameters (FA, MD) in different white matter regions can diagnose and detect white matter changes in excessive smartphone users even when conventional MRI data are normal. This study demonstrates the recent noninvasive MRI technique value while revealing covered brain white matter alterations in Egyptian youth due to smartphone overuse.

Keywords MRI, DTI, Diffusion tensor imaging, Fractional anisotropy, Mean diffusivity, Smartphone dependency, Egyptian youth

Background

Dependency now extends beyond drug or chemical abuse to encompass behavioral addictions, involving betting, internet, gaming, as well as smartphones, especially among youth. These conditions require early diagnosis and treatment [1].

Smartphone addiction is increasingly regarded as an important psychological issue, with unclear neural substrates [2]. Around 1380 Egyptian undergraduates from various universities have been involved in a

*Correspondence:
Alaa Mohamed Reda
Alaa.khalil@med.tanta.edu.eg
[1] Radiodiagnosis and Medical Imaging, Faculty of Medicine, Tanta University, El-Geish Street, Tanta, Gharbia Governorate, Egypt
[2] Psychiatry department, Tanta University, El-Geish Street, Tanta, Gharbia Governorate, Egypt

representative sample. Okasha et al. [3] addressed the smartphone addiction prevalence reached about 60% between students, with significant poor consequences on their psychological health.

Egypt possesses the most internet as well as cellphones consumers in the Middle East besides North Africa regions. Out of the total population, 52% or 59 million people are internet users, and 92.7% or 95.75 million people have mobile connections. These numbers show the growth and adoption of digital technologies in Egypt [4].

Smart phone addiction scale (SAS), as indicated by Kwon et al. [2], represents a tool developed to detect those who possess higher chances of smartphone addiction and to determine the addiction level. Additionally, high-resolution MRI remains a beneficial imaging modality helping better understand such disease. Compared to controls, smartphone-dependent individuals exhibited decreased white matter integrity within numerous brain areas, involving the superior longitudinal fasciculus (SLF), superior corona radiata (SCR), internal and external capsules, sagittal stratum, fornix/stria terminalis, as well as midbrain structures [5]. Furthermore, studies exhibited the white matter impairment degree in the internal capsule as well as stria terminalis was linked to smartphone dependence severity as well as related behavioral measures [6]. These findings suggest that white matter alterations in smartphone dependence may underlie the cognitive and emotional deficits observed in this condition [7].

Clinical assessment of patient symptoms has been the main basis for diagnosis for many years [8]. Previous research on internet addiction has examined its behavioral, social, and clinical aspects, as well as its treatment options [9]. However, recent technologies regarding high-resolution MRI have enabled more precise and sensitive detection of structural and functional brain alterations linked to internet addiction [7]. DTI is a novel approach that can quantify white matter integrity through assessing fractional anisotropy, mean diffusivity, as well as ADC values in specific brain areas [10].

Our study had two aims: (1) to use DTI to assess white matter differences between Egyptian youth with SPD and healthy controls; and (2) to validate the Egyptian version of the smart phone addiction scale-short version (SAS-SV) for youth.

Methods

This prospective case control study took place within the timeframe of January 1st, 2022, to March 1st, 2023, following ethical committee approval of our institution. Participants went through filling in an informed consent after exhibiting procedure benefits. We ensured the participants' data privacy as well as confidentiality and used them only for scientific purposes. We also monitored the data provision throughout the study.

All cases and volunteers went through MRI utilizing 1.5 Tesla MRI unit GE machine featuring a closed magnet.

Inclusion criteria

Patients with smart phone dependency in Egyptian youth population, in faculty of medicine of our university of different educational stages (from 1st to last year). The first group consisted of 53 medical students who had educational or social problems due to smart phone dependence and were referred by the psychiatry department in our hospital. We also recruited 25 volunteers representing a control group. They were carefully selected for both age and sex to resemble the 1st group.

Exclusion criteria

We excluded patients who had mental illness due to organic lesions, involving neoplasms or vascular lesions, and those having claustrophobia or MR-incompatible metallic devices, cardiac pacemakers or cochlear implants. Also, any individuals with history of previous psychiatric disorders or mental problems (as psychosis, schizophrenia) were excluded from our study.

Data collection

We collected full history from each patient, including personal history, initiation, progression as well as existing symptoms duration, previous psychiatric diseases history, observed systemic diseases or neurological disorders, medications, and previous physical or psychiatric traumas.

We reviewed any previous radiological examinations or investigations for each patient.

Clinical examination

A full psychiatric examination was performed by a consultant possessing 10 years of experience within the psychiatry field. Radiologists remained unaware of participants' age, identity, as well as their clinical data according to SAS-SV scoring. This scale aimed at identifying and assessing cellphones dependence risk. The SAS-SV represents 10-item scale evaluating the smartphone addiction risks utilizing a 6-point Likert scale, so (1) exhibits strong disagreement while (6) exhibits strong agreement. Therefore, greater scores often exhibit

problematic smartphone usage. We established an English SAS-SV translation into Arabic, making necessary adjustments for local context, as well as subsequently completed a reverse translation.

MRI examination

Patients did not need any specific preparation before MRI.

We employed a conventional 16-channel head coil along with foam padding for reducing possible head movements. Participants underwent metal pins removal as well as positioned themselves in a supine posture, entering the machine headfirst. Slice thickness exhibited 4 mm, matrix size was 256 × 256, while the FOV ranged between 220 and 240 mm. The MRI protocol included the following sequences: Axial T1WI possess a (TR) of 300–600 ms, a (TE) of 10–30 ms. Axial T2WI possessing a (TR) of 700–2000 ms, a (TE) of 80–100 ms. Additionally, while axial and/or coronal oblique (FLAIR) possessing a TR of 6000–8000 ms, a TE of 140 ms, as well as (TI) of 1400 ms. DWI was conducted with varying diffusion-sensitizing gradient strengths, shown by different b-values (0, 1000). DTI: acquisition was accomplished utilizing a high-resolution 3D T1-weighted spoiled gradient echo pulse sequence. The parameters utilized involved (TR) of 9.7 ms, (TE) of 4.6 ms, (TI) of 400 ms, and a flip angle (θ) of 35°. The acquisition involved 124 slices, each 0.8 mm thick, with a matrix size of 208 × 170. (FOV) was 23 cm, as well as there were 260 contiguous sections (acquisition time min). DTI sequence involved single-shot spin echo-planar sequence in forty encoding directions based on these criteria: TR is 8830 ms; TE is 80 ms; acquisition matrix is 112 × 110 mm; acquisition voxel is 2.00/2.03/2.00 mm; FOV: right–left is 224 mm, anteroposterior is 224 mm, feet–head is 120 mm; voxel size: right–left is two mm, anteroposterior is two mm, slice thickness is two mm, reconstruction voxel size is 1.75 mm, *b*-value is 800 mm/s, as well as number of slices is sixty.

Data processing as well as images analysis

DTI dataset were transfered to the workstation (advantage window 4.7, GE Medical Systems) and then transformed into color-coded map images; several DTI indices involving FA as well as MD have been produced. Delineating (ROIs) was accomplished within observable white matter areas.

Calculating DTIs of every ROI was accomplished then performed a comparison between them as well as equivalent ROIs within contralateral hemisphere. Moreover, the tracks anatomy as well as direction were observed in the directionally encoded FA maps, tracts running in three orthogonal planes are allocated a distinct color. Analysis of color-coded DTI maps was accomplished accomplished, both subjective evaluation through visual comparison as well as quantitative assessment through comparing FA as well as MD measurements within normal opposite hemisphere. Data underwent thorough analysis as well as interpretation by two independent highly skilled neuroradiologists, each with 9 and 10 years of experience within such field. Final decision taken by another third experienced consultant in neuroradiology, possessing 12 years of experience in advanced neuroimaging who provided his point of view regarding cases with conflicting viewpoints.

Every patient was assigned a unique identification number, with all their data anonymized.

Statistical analysis

The data underwent statistical analysis utilizing SPSS for Windows version 28.0 (SPSS Inc, Chicago, IL). Categorical variables were described as frequency as well as proportion while quantitative variables as mean, SD as well as range. We utilized the Student t test for performing quantitative data comparison, while the Chi square test (χ^2) was applied for categorical data comparison. We set the significance level ($p < 0.05$). We used the independent *t* test for two independent groups comparison. We used ROC curve analysis for identifying optimal cut-off values as well as maximal AUC for FA and MD in assessing early white matter changes in Egyptian youth with SPD. We also evaluated the diagnostic accuracy, sensitivity, specificity and accuracy of FA and MD.

Results

This study included 53 students with smart phone dependence (SPD group) as well as twenty-five healthy controls with age and sex matching SPD group. SPD individuals and controls were right-handed. The SPD group mean age exhibited 20.54 ± 1.56 years, while 20.48 ± 1.61 years in the control group, there was mild sex prediction to males in the two groups (69.8%; $n = 37$ of the SPD group while 56%; $n = 14$ of the control one). No statistically significant variations were documented among both groups regarding age ($p = 0.87$) as well as sex ($p = 0.231$) (Table 1).

The individual SAS-SV items' scores as well as the total score were significantly greater within the SPD group as opposed to the control one. The median total score within SPD group exhibited 33, while controls exhibited 17, at a p value of < 0.001 as shown in Table 2.

Table 1 The sociodemographic data of the studied cases

	SPD group (*N* = 53)	Control group (*N* = 25)	Test	*p* value
Age (year)				
Mean ± SD, median (IQR)	20.54 ± 1.56 years, 21 (19–22)	20.48 ± 1.61 years, 20 (19–22)	647.5[a]	0.87
Sex				
Female	16 (31.2%)	11 (44%)	1.432[b]	0.231
Male	37 (69.8%)	14 (56%)		

N number, *SD* standard deviation

[a] Mann–Whitney test

[b] Chi-square test

Table 2 The SAS-SV scores in the studied participants

SAS-SV scores, median (IQR)	Patients group (N = 53) median, IQR	Control group (N = 25) median, IQR	Mann–Whitney test	*p* value
Missing planned work due to smartphone use	3 (3–3)	2 (2–2)	126	< 0.001*
Having a hard time concentrating in class, while doing assignments, or while working due to smartphone use	3 (3–3)	2 (2–2)	164.5	< 0.001*
Feeling pain in the wrists or at the back of the neck while using a smartphone	3 (3–4)	2 (1–2)	183	< 0.001*
Won't be able to stand not having a smartphone	3 (2–3)	2 (2–2)	133	< 0.001*
Feeling impatient and fretful when I am not holding my smartphone	3 (3–4)	2 (1–2)	108.5	< 0.001*
Having my smartphone in my mind even when I am not using it	3 (3–5)	2 (1–2)	55	< 0.001*
I will never give up using my smartphone even when my daily life is already greatly affected by it	3 (3–5)	2 (1–2)	123.5	< 0.001*
Constantly checking my smartphone so as not to miss conversations between other people on WhatsApp, Facebook, or WeChat	3 (3–5)	1 (1–2)	109.5	< 0.001*
Using my smartphone longer than I had intended	3 (3–4)	2 (1–2)	82.5	< 0.001*
The people around me tell me that I use my smartphone too much	3 (2–4)	2 (2–2)	180	< 0.001*
Total score	33 (32–36)	17 (15–19)	0.0	< 0.001*

IQR inter-quartile range, *a* independent *t* test, *N* number

*Statistically significant

Regarding SPD group, the studied white matter regions of interest (ROI), mean FA values were less as opposed to controls. This difference reached statistical significance in the fornix ($p < 0.001$*), right SLF ($p < 0.001$*), left superior longitudinal fasciculus (SLF) ($p = 0.006$*), right superior corona radiata (SCR) ($p = 0.044$*), right superior cerebellar peduncle (SCP) ($p = 0.002$*), left superior cerebellar peduncle (SCP) ($p = 0.002$*), EC ($p < 0.001$*), posterior limb of internal capsule (PLIC) ($p = 0.002$*), and medial lemniscus (ML) ($p = 0.031$*), while greater mean diffusivity (MD) values within SPD group were documented as opposed to controls, with statistically significant differences regarding fornix ($p < 0.001$*), left superior corona radiata (SCR) ($p = 0.047$*), right superior cerebellar peduncle (SCP) ($p < 0.001$*), left superior cerebellar peduncle (SCP) ($p < 0.001$*), external capsule (EC) ($p < 0.001$*), and posterior limb of internal capsule (PLIC) ($p < 0.001$*) as illustrated in Table 3.

Diagnostic performance evaluation regarding measured fractional anisotropy (FA) demonstrated that the greatest area under curve was for fornix (0.903, $p < 0.001$*), in which an FA value of 0.43 at the region of the fornix was able to diagnose the smart phone dependence with a sensitivity of 90.6% and a specificity of 96%, followed by the EC (AUC = 0.836, $p < 0.001$), in which an FA of 0.51 at the EC ROI exhibited sensitivity of 90.6% as well as specificity of 84% as described in Fig. 1.

Table 3 The DTI parameters in the studied participants

	SPD group (N = 53) mean ± SD	Control group (N = 25) mean ± SD	Independent *t* test	*p* value
FA				
Fornix	0.295 ± 0.08	0.455 ± 0. 06	8.94	< 0.001*
SLF				
Right	0.309 ± 0.09	0.392 ± 0.11	3.54	< 0.001*
Left	0.318 ± 0.1	0.398 ± 0.12	2.6	0.006*
SCR				
Right	0.362 ± 0.091	0.417 ± 0.14	2.05	0.044*
Left	0.362 ± 0.094	0.408 ± 0.14	1.74	0.086
SCP				
Right	0.412 ± 0.091	0.497 ± 0.14	2.96	0.002*
Left	0.417 ± 0.1	0.499 ± 0.13	2.96	0.002*
MCP				
Right	0.469 ± 0.13	0.526 ± 0.11	1.89	0.062
Left	0.465 ± 0.12	0.519 ± 0.13	2.45	0.075
EC	0.414 ± 0.08	0.592 ± 0.12	7.1	< 0.001*
ALIC	0.412 ± 0.09	0.458 ± 0.14	1.74	0.086
PLIC	0.455 ± 0.1	0.531 ± 0.11	3.05	0.002*
ML	0.419 ± 0.1	0.476 ± 0.12	2.2	0.031*
$MD * 10^{-3}\ mm^2\ S^{-1}$				
Fornix	1.32 ± 0.22	1.01 ± 0.34	4.84	< 0.001*
SLF				
Right	0.843 ± 0.13	0.794 ± 0.17	1.38	0.17
Left	0.841 ± 0.14	0.797 ± 0.17	0.73	0.23
SCR				
Right	0.834 ± 0.12	0.778 ± 0.14	1.799	0.076
Left	0.837 ± 0.13	0.77 ± 0.15	2.02	0.047*
SCP				
Right	0.753 ± 0.12	0.652 ± 0.14	3.36	< 0.001*
Left	0.754 ± 0.12	0.702 ± 0.13	3.34	< 0.001*
MCP				
Right	0.773 ± 0.12	0.718 ± 0.14	1.789	0.078
Left	0.767 ± 0.12	0.719 ± 0.15	1.52	0.133
EC	1.22 ± 0.35	0.79 ± 0.14	6.08	< 0.001*
ALIC	0.84 ± 0.13	0.783 ± 0.15	1.72	0.09
PLIC	0.868 ± 0.11	0.766 ± 0.15	3.38	< 0.001*
ML	0.874 ± 0.12	0.818 ± 0.14	1.8	0.076

SLF superior longitudinal fasciculus, *SCR* superior corona radiata, *SCP* superior cerebellar peduncle, *MCP* middle cerebellar peduncle, *EC* external capsule, *ALIC* anterior limb internal capsule, *PLIC* posterior limb internal capsule, *ML* medial lemniscus

*Statistically significant

The diagnostic performance of fornix FA and EC FA within the AUC was significantly greater as opposed to all the other tested regions, while no significant difference was found between each other ($p = 0.344$) as mentioned in Table 4 that shows paired-sample area variations under the ROC curves.

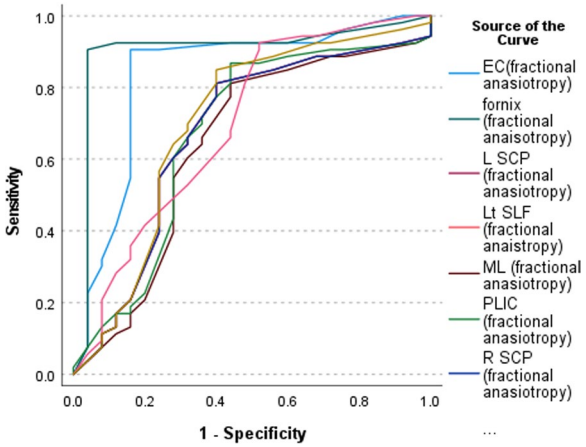

Fig. 1 ROC (receiver operating characteristic curve) analysis for the diagnostic performance of FA parameter in prediction of diseased cases. FA: Fractional anisotropy, MD: Mean diffusivity

Diagnostic performance of R SCP MD was significantly greater as opposed to L SCR MD ($p = 0.014$), that of EC MD was significantly higher than L SCR MD ($p < 0.001$), R SCP MD ($p = 0.004$), and PLIC MD ($p = 0.003$), and that of fornix MD was significantly greater as opposed to L SCR ($p = 0.003$), as illustrated in Table 5 (Figs. 2).

Discussion

Smartphones offer unprecedented flexible access to information and communication, but they may also cause a new kind of dependence. This addiction may be related to the rapidly evolving media technology [11]. To assess this addiction in clinical and psychiatric settings, various measuring tools have been developed. Within our study, we utilized the (SAS-SV) along with psychological evaluation by experts. The SAS-SV was initially created in Korean and translated into English [12]. It has also been validated in other languages, including Arabic [13]. Therefore, it can capture smartphone dependence across different cultures with validity and reliability [14].

Nevertheless, there is still a significant knowledge gap about the neurological mechanisms underpinning potential smartphone addiction, hindering effective interventions to curb excess phone usage [15].

Neuroimaging techniques, particularly MRI, have explored the correlation between excess smartphone usage as well as neurological functional and structural variations [16].

Our research aimed at investigating the possible neural abnormalities as well as early white matter changes in young medical students with smartphone dependence, using functional MRI with DTI. As far as we know, there have been no prior Egyptian research assessing the

Table 4 Paired-sample area difference under the ROC curves

Test result pair(s)	Test difference		AUC difference	95% (C.I.) confidence interval	
	z	*p* value		Lower bound	Upper bound
Fornix versus R SLF	2.357	.018*	.201	.034	.368
Fornix versus L SLF	2.697	.007*	.230	.063	.397
Fornix versus R SCR	2.506	.012*	.207	.045	.369
Fornix versus R SCP	2.697	.007*	.230	.063	.397
Fornix versus L SCP	2.697	.007*	.230	.063	.397
Fornix versus EC	.947	.344	.068	− .072	.207
Fornix versus PLIC	2.602	.009*	.232	.057	.407
Fornix versus ML	2.972	.003*	.264	.090	.438
L SLF versus R SLF	1.411	.158	.029	− .011	.069
R SLF versus R SCR	.086	.932	.006	− .132	.144
R SLF versus R SCP	1.411	.158	.029	− .011	.069
R SLF versus L SCP	1.411	.158	.029	− .011	.069
R SLF versus EC	− 1.873	.061	− .134	− .273	.006
R SLF versus PLIC	.489	.625	.031	− .093	.155
R SLF versus ML	1.030	.303	.063	− .057	.182
L SLF versus R SCR	− .322	.748	− .023	− .163	.117
L SLF versus R SCP	.000	1.000	.000		
L SLF versus L SCP	.000	1.000	.000		
L SLF versus EC	− 2.257	.024*	− .163	− .304	− .021
L SLF versus PLIC	.032	.974	.002	− .113	.117
L SLF versus ML	.595	.552	.034	− .077	.144
R SCR versus R SCP	0.321	.748	.023	− .117	.163
R SCR versus L SCP	0.32	.748	.023	− .117	.163
R SCR versus EC	− 2.13	.033*	− .140	− .268	− .011
R SCR versus PLIC	0.297	.767	.025	− .140	.189
R SCR versus ML	0.69	.490	.057	− .104	.217
R SCP versus L SCP	.000	1.000	.000		
R SCP versus EC	− 2.257	.024*	− .163	− .304	− .021
R SCP versus PLIC	.032	.974	.002	− .113	.117
R SCP versus ML	.595	.552	.034	− .077	.144
L SCP versus EC	− 2.257	.024*	− .163	− .304	− .021
L SCP versus PLIC	.032	.974	.002	− .113	.117
L SCP versus ML	.595	.552	.034	− .077	.144
EC versus PLIC	2.095	.036*	.165	.011	.318
EC versus ML	2.548	.011	.196	.045	.347
PLIC versus ML	1.492	.136	.032	− .010	.073

AUC area under curve, *C.I.* confidence interval, *SLF* superior longitudinal fasciculus, *SCR* superior corona radiata, *SCP* superior cerebellar peduncle, *MCP* middle cerebellar peduncle, *EC* external capsule, *ALIC* anterior limb internal capsule, *PLIC* posterior limb internal capsule, *ML* medial lemniscus

*Statistically significant

DTI quantitative parameters diagnostic accuracy (FA and MD) in smartphone dependence cases. DTI identifies white matter tract organization integrity [17]. Our study addressed, SPD group exhibited significantly less FA measurements regarding fornix, SLFs, SCR, SCP, EC, PLIC, and medial lemniscus (ML), and significantly greater MD measurements regarding SCR, SCP, EC, and PLIC. These findings suggest these anatomical regions are affected in individuals with SPD. In this study, the quantitative DTI assessment of various neural structures demonstrated a reproducible diagnostic performance of FA in fornix and EC and MD in fornix, EC, SCP, and PLIC for the prediction of smart phones dependence (Figs. 3, 4, 5).

Table 5 Paired-sample area difference under the ROC curves

Test result pair(s)	Test difference		AUC difference	95% confidence interval	
	z	*p* value		Lower bound	Upper bound
L SCR versus R SCP	−2.454	.014*	−.132	−.238	−.027
L SCR versus EC	−4.045	< 0.001*	−.309	−.459	−.159
L SCR versus PLIC	−1.558	.119	−.128	−.290	.033
L SCR versus fornix	−2.962	.003*	−.247	−.411	−.084
R SCP versus EC	−2.900	.004*	−.177	−.296	−.057
R SCP versus PLIC	.068	.945	.004	−.115	.123
R SCP versus fornix	−1.585	.113	−.115	−.257	.027
EC versus PLIC	3.001	.003*	.181	.063	.299
EC versus fornix	1.485	.138	.062	−.020	.144
PLIC versus fornix	−1.451	.147	−.119	−.279	.042

AUC area under curve, *C.I.* confidence interval, *SLF* superior longitudinal fasciculus, *SCR* superior corona radiata, *SCP* superior cerebellar peduncle, *MCP* middle cerebellar peduncle, *EC* external capsule, *ALIC* anterior limb internal capsule, *PLIC* posterior limb internal capsule, *ML* medial lemniscus

*Statistically significant

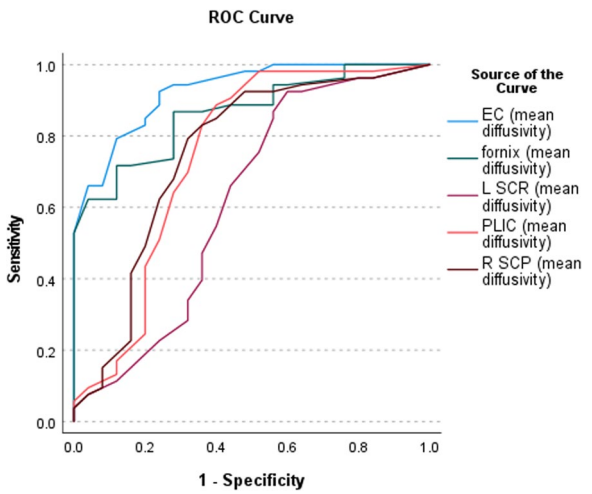

Fig. 2 ROC analysis for the diagnostic performance of MD in prediction of cases of dependency

Few studies have used DTI to assess individuals with smartphone dependence, and they have reported variable results. Few studies could be reached in this context. Wang et al. [11] found that the hippocampal cingulum bundle fibers FA as well as AD measurements exhibited significant decrease within SPD individuals. In the current study it was shown that FA values were significant reduction, as well as MD measurements were significantly greater within SMD individuals as opposed to controls regarding SLF, SCR, ALIC, PLIC, EC, sagittal stratum, fornix, SLP, MCP, and ML [12]. Such findings aligned with ours. Recently, the right amygdala node centrality, as well as the body of corpus callosum, was found to be affected with DTI alteration as found by Tymofiyeva et al. [13] and Zou et al. [14], respectively.

The internal capsule, medial lemniscus and cerebellar peduncles are white matter tracts that mediate proprioceptive functions and sensorimotor integrity. Any alteration could lead to impaired proprioceptive functions and disturbed sensorimotor integrity [17]. These alterations are common in SPD individuals [18]. The SLF links the frontal, parietal, temporal, as well as occipital lobes [19], thus mediating emotions, memory, attention, and language processes [20]. Fornix represents a white matter bundle linking the limbic system several nodes, thus having an essential part regarding cognitive function [21]. These functions are affected in SPD individuals [22].

(See figure on next page.)

Fig. 3 An 18-year-old male patient who was clinically diagnosed as a smart phone dependent, underwent clinical psychiatric evaluation according to SAS-SV that was 33. The structural MR images, including axial T2WI (**A**) that is unremarkable and negative. Axial and coronal directionally encoded color maps (**B**, **C**) indicate the directions of fiber tracts (red transverse, blue cranio-caudal, green antero-posterior). Axial FA map (**D**) reveal focal decrease in FA values in superior longitudinal fasciculus (SLF), anterior and posterior limbs of internal capsule (ALIC) and (PLIC), external capsule (EC) (white arrows), Axial FA map (**E**) reveals focal decrease in the FA value in superior and middle cerebellar peduncles (SCP and MCP) and medial lemniscus fasciculus (ML) (white arrows). Coronal FA map (**F**) revealed focal decrease in the FA value in the fornix (FX), superior and middle cerebellar peduncles (SCP and MCP) and superior corona radiata (SCR) (white arrows), while axial and coronal MD maps (**G**, **H**) reveal focal increase in MD values in anterior and posterior limbs of internal capsule (ALIC) and (PLIC), External capsule (EC) and fornix (FX), (white arrows)

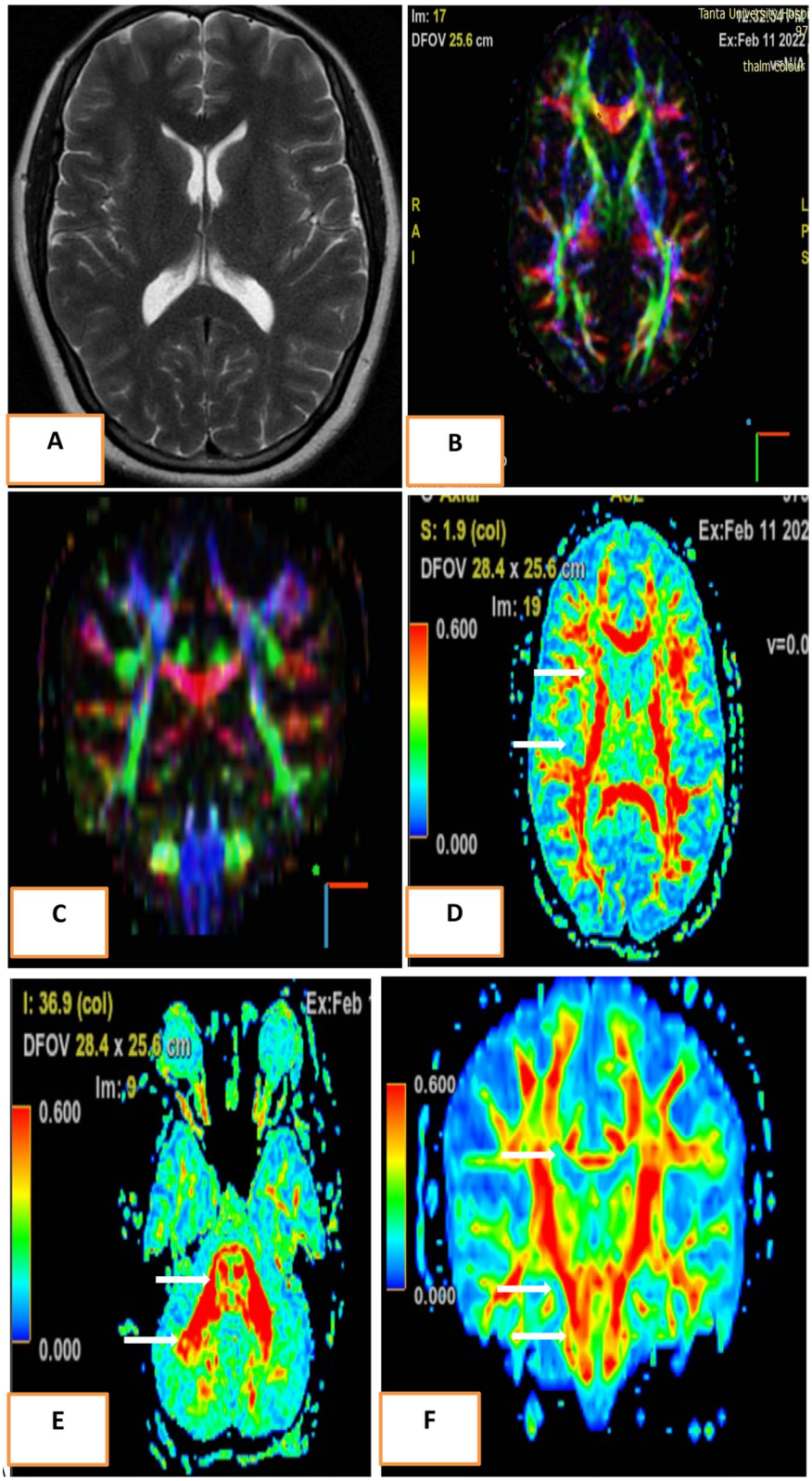

Fig. 3 (See legend on previous page.)

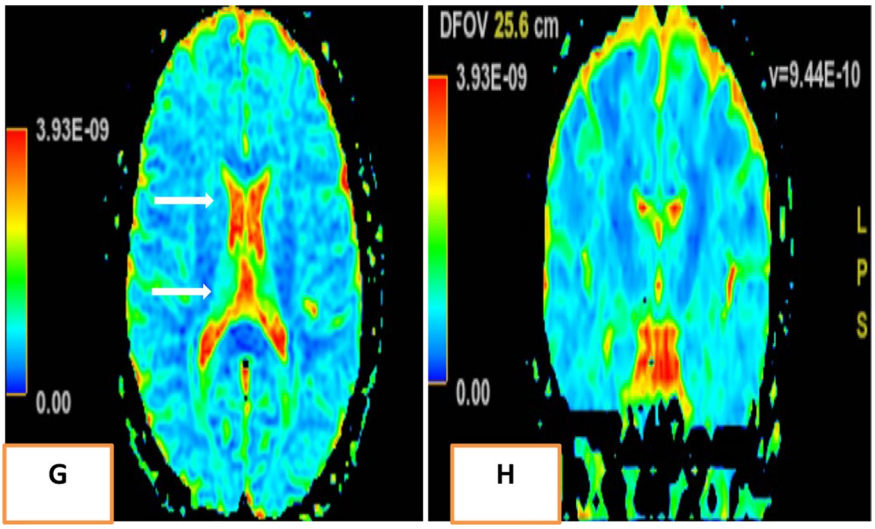

Fig. 3 continued

The external capsule is a bundle that connects the cerebral cortex and the striatum [23]. Damaged EC fibers may impair cognitive and emotional functions and lead to substance addiction [24]. The internal capsule is a vital structure with many sensory and motor projection fibers [25]. Consistent with our study, previous studies have reported internal capsule damage in various addictions, such as gambling and Internet addiction [26].

Limitations

Our research involved a relatively small sample size. Nevertheless, this work extended current knowledge about using functional MRI parameters in the understanding of the underlying neurological mechanisms implicated in SPD and diagnosis of individuals having this addiction in a sample of Egyptian medical students in faculty of medicine. Recruiting medical school students was also another challenging limitation, as many personnels refused to perform the examination.

Recommendations

- To confirm these findings, further data collection with a larger and more diverse sample, longer duration and multiple assessment points is needed and on samples of different age groups, with follow-up assessment after behavioral therapy.
- Future research should also use different MRI machines with higher Tesla in multiple locations for validation of data and results.

Conclusions

Combining quantitative DTI parameters (FA, MD) in different white matter regions can detect white matter changes in excessive smartphone users even when conventional MRI data are normal. This study demonstrates the usefulness of the new noninvasive MRI technique to reveal hidden brain pathology and white matter changes in Egyptian youth from smartphone overuse.

(See figure on next page.)

Fig. 4 A 20-year-old female patient who was clinically diagnosed to be smart phone dependent, underwent clinical psychiatric evaluation according to SAS-SV that was 35. Axial directionally encoded color map (**A**) indicates directions of fiber tracts of left external capsule (EX) represented by green color, means; antero-posterior direction. Axial FA map (**B**) reveals focal decrease in the FA value in the left external capsule measures = 0.39 (white arrow). Axial MD map (**C**) reveals a focal increase in the MD value in the left external capsule measures = 1.19×10^{-3} mm^2/s, (white arrow), denoting early white matter changes in it, which is highly significant for smart phone dependency. Axial directionally encoded color map (**D**) indicates the directions of fiber tracts of left superior longitudinal fasciculus (SLF) presented with green color that means it is antero-posterior in direction. Axial FA map (**E**) reveals a focal decrease in the FA value in the left superior longitudinal fasciculus measures = 0.3 (white arrow). Axial MD map (**F**) reveals a focal increase in the MD value in the left superior longitudinal fasciculus measures = 0.85×10^{-3} mm^2/s (white arrow), denoting early white matter changes in it

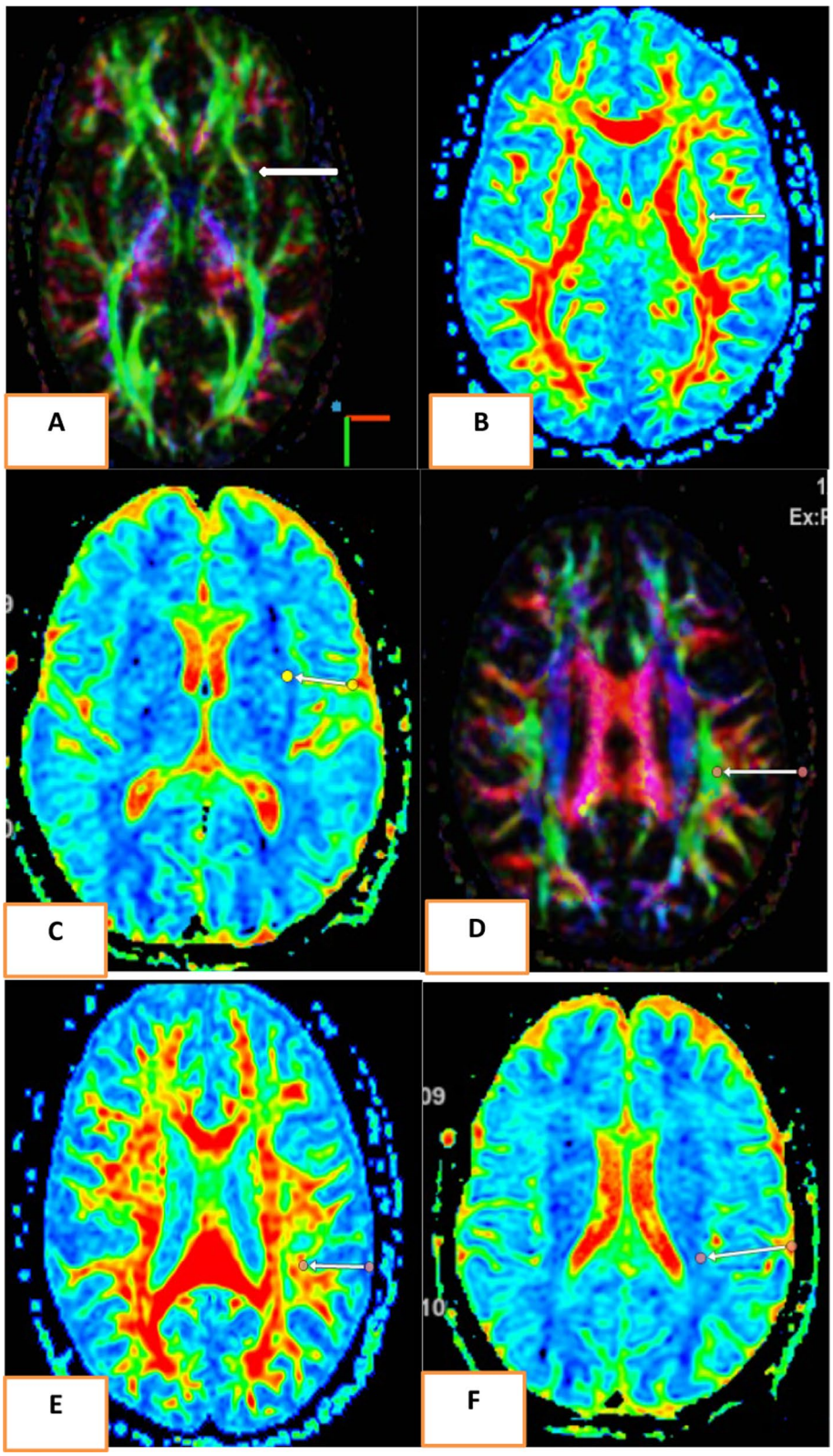

Fig. 4 (See legend on previous page.)

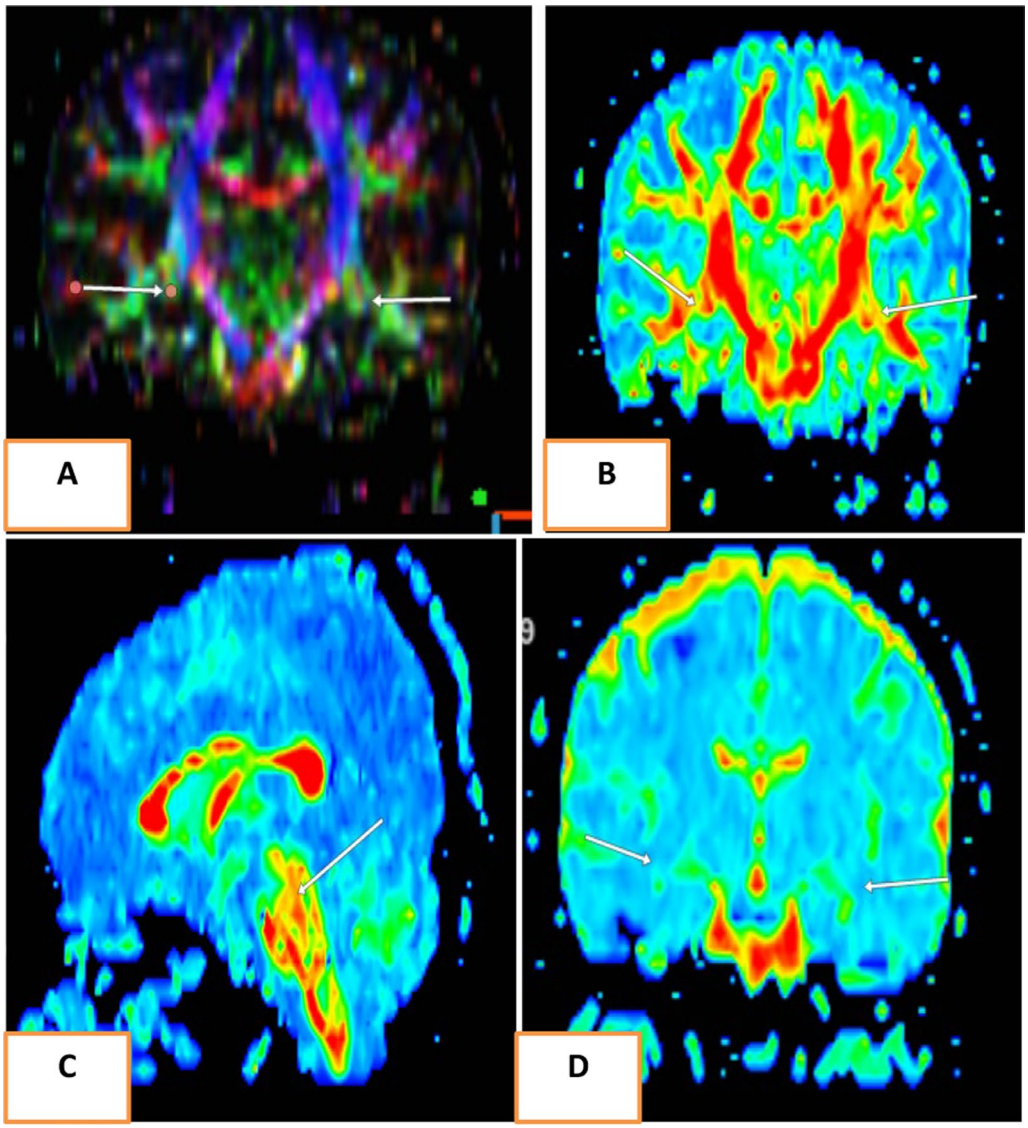

Fig. 5 An 18-year-old female patient clinically diagnosed to be smart phone dependent. On clinical psychiatric assessment, her SAS-SV score was 36. Coronal directionally encoded color map (**A**) indicates the directions of fiber tract of Fornix (FX) (presented with green color that means it has antero-posterior direction). Coronal and sagittal FA maps (**B**, **C**) reveal focal decrease in the FA values of the Fornix that measures = 0.26 (white arrows). Coronal MD map (**D**) reveals focal increase in the MD value in the Fornix that measures 1.22×10^{-3} mm^2/s (white arrows), denoting early white matter changes in the fornix

Abbreviations

MRI	Magnetic resonance imaging
FLAIR	Fluid-attenuated inversion recovery
SD	Standard deviation
DTI	Diffusion tensor imaging
FA	Fractional anisotropy
MD	Mean diffusivity
SAS-SV	Smart phone addiction scale-short version
SPD	Smart phone dependence
*	Statistically significant
AUC	Area under curve
C.I.	Confidence interval
SLF	Superior longitudinal fasciculus
SCR	Superior corona radiate
SCP	Superior cerebellar peduncle
MCP	Middle cerebellar peduncle
EC	External capsule
ALIC	Anterior limb internal capsule
PLIC	Posterior limb internal capsule
ML	Medial lemniscus

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Author contributions
AR suggested the research idea, ensured the original figures and data in the work, minimized the obstacles to the team of work, correlated the study concept and design and had the major role in analysis. AE supervised the study with significant contribution to design the methodology, manuscript

revision and preparation. MM correlated the clinical data of patient, matched it with the findings, and drafted and revised the work. SE collected data in all stages of manuscript and performed data analysis. All authors have read and approved the manuscript"and ensured that this is the case.

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Availability of data and materials
The authors confirm that all data supporting the finding of the study are available within the article and the raw data supporting the findings were generated and available at the corresponding author on request.

Declarations

Ethics approval and consent to participate
Informed written consents were taken from the patients and healthy volunteers; the study was approved by ethical committee of Tanta University hospital, faculty of medicine (number: 35965/10/22).

Consent for publication
All participants included in the research gave written consent to publish the data included in the study. Authors accepted to publish the paper.

Competing interests
The authors declare that they have no competing of interests.

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