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Early Prediction of Functional Outcome after Cerebral Small Arteries Infarctions Using Diffusion Tensor MRI Tractography

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Abstract

Background: Lacunar Infarctions (LIs) are ischemic strokes caused by occlusion of the deep penetrating arteries. They constitute about 25% of all ischemic strokes and have variable consequences based on affected tracts disruptions.

Aim of Study: Were to assess the role of MRI Diffusion Tensor Imaging (DTI) fiber tractography as an early biomarker of LIs prognosis.

Patients and Methods: This work was conducted on 42 first-ever symptomatic motor or sensorimotor LIs patients (3 1 male and 11 female) submitted to stroke severity assessment using the National Institute of Health Stroke Scale (NIHSS), carotid duplex, brain MRI to determine LIs dimeter and occult small vessel disease imaging markers. Corticospinal Diffusion Tensor Tractography (CS-DTT) was done within 48 hours from stroke onset. Thirty-eight patients continued a 3-months follow-up schedule, at the end of which their physical dependences were assessed using the Modified Barthel Index (MBI) scale which were compared with the baseline assessment parameters to determine the prognostic biomarkers.

Results: Dependent patients' group showed significant increase in their age, BMI, carotid intima media thickness and white matter hyperintensities grade than independent patients' group. The FA ratio was the earliest parameter showed significant changes which were lower in dependent than independent patients' groups. On the other hand, each of ipsilateral DTI fractional anisotropy, mean diffusivity and fiber number showed non-significant differences.

Conclusion: Factors associated with poorer functional outcome after newly diagnosed LIs include advanced age, hypertension, obesity, premorbid physical inactivity, increased CIMT and the presence of imaging biomarkers of occult SVD. Reduced ipsilateral/contralateral FA ratio of the CS-DTT is a reliable early predictor of short-term functional outcome and motor disability after motor and sensorimotor LIs.

Key Words: *Lacunar infarcts – Diffusion tensor imaging – Corti co-spinal tractography – Modified barthel index – Post-stroke physical disabilities.*

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Introduction

ISCHEMIC cerebrovascular stroke is defined as an episode of neurological dysfunction caused by focal cerebral, spinal or retinal infarction [1]. Stroke is the 2nd cause of death worldwide, the 3 rd cause of prolonged disability and is responsible for 4.5% of Disability-Adjusted Life-Years (DALYs) from all medical causes globally [2]. Nearly 20% of stroke survivors are unable to return to work, 30% need daily living assistance and 16% require institutional care [3]. Lacunar Infarctions (LIs) are small volume subcortical infarctions, 3-15mm in diameter caused by occlusion of the small deep penetrating arteries. They may be occult LIs (asymptomatic) or clinically presented by either transient ischemic attacks or one of the lacunar syndromes including pure motor hemiparesis (the most common), pure sensory stroke, sensorimotor stroke, ataxic hemiparesis and dysarthria-clumsy hand syndrome [4,5].

Diffusion Tensor Imaging (DTI) is a MRI sequence specifically evaluate the directionality and integrity of brain axonal fibers and networks strength in case of neuronal injury due to various etiologies including stroke. The data related to the

Abbreviations:

AADLs	: Advanced Activities of Daily Living Scale.
ARWMC	: Age-Related White Matter Changes.
CIMT	: Carotid Intima Media Thickness.
CS-DTT	: Corticospinal Diffusion Tensor Tractography.
DTI	: Diffusion Tensor Imaging.
FA	: Fractional Anisotropy.
FN	: Fiber Number.
LIs	: Lacunar Infarctions.
MBI	: Modified Barthel Index.
MD	: Mean Diffusivity.
NIHSS	: National Institute of Health Stroke Scale.
SVD	: Small Vessel Disease.
WMHs	: White Matter Hyperintensities.

value of DTI in anticipating the degree of motor disabilities and functional outcome after corticospinal tract disruption due to cerebral infarction are contradictory [6].

Patients and Methods

This paper is adapted from the thesis with the same title submitted by the first author to the Faculty of Medicine, Tanta University, in partial fulfillment of the Master's Degree in Diagnostic Radiology. The work was a prospective study conducted on 42 patients (31 male and 11 female) with 1st ever symptomatic pure motor or sensorimotor LIs admitted to the Neurovascular Units and/or the ICUs of the Neurology Department, Tanta University Hospitals in the period from November 2017 till June 2018.

Exclusion criteria included patients received intravenous thrombolysis (to keep homogeneity of the studied sample) as well as patients with recurrent stroke, CADASIL disease, MRI contraindications, preexisting physical disability, cognitive impairment or psychiatric disorders. Vitally unstable patients and those with advanced renal, hepatic, chest or cardiac diseases were also excluded.

The study's protocol was approved by the Research Ethics Committee and Quality Assurance Unit, Faculty of Medicine, Tanta University. Participations were voluntary, informed consents were obtained from all included patients and the possible risks were clarified.

Patients were submitted to history taking, pre-stroke basic Activities of Daily Living (ADL) assessment using the Advanced Activities of Daily Living Scale (AADLs) [7], complete neurological examination and stroke severity assessment using the National Institute of Health Stroke Scale (NIHSS). The mean common Carotid Intima Media Thickness (CIMT) was measured by the calculating the average of multiple bilateral measurements in area away from atheromatous plaques (if present). The maneuver was done using linear array transducer of multi-frequency 3-12MHz, real time, sagittal, coronal and axial views, Ultrasound Philips. Model: HD 11TM XE, Germany.

Brain MRI were done to confirm the diagnosis of recent LIs and determine their sizes as well as their locations. White Matter Hyperintensities (WMHs) were graded using the Age-Related White Matter Changes (ARWMC) visual rating scale (supplementary material-1) [8]. Brain MRI was performed using GE Healthcare, Milwaukee, WI, USA. The images were attained by a 1.5-Tesla, General Electric Scanner (GE Medical Systems, Milwaukee, USA) with quadrature 8 channels head coil included axial T1 and T2 weighted fast spin-echo, 3-D FLAIR, and diffusion weighted images (DWI) using strong gradient strength [high b-values=1000 seconds/millimeter 2 (s/mm^2)] with estimation of the associated Apparent Diffusion Coefficient (ADC) value.

Corticospinal diffusion tensor tractography (CS-DTT) were done within 48 hours from stroke onset to measure the Fractional Anisotropy (FA), Mean Diffusivity (MD) and Fiber Number (FN) in the region of abnormality compared to the contralateral hemisphere. The DTI sequence was done by single-shot spin echo-planar imaging with TR 8830msec., TE 80msec., acquisition matrix 112 X 110mm, acquisition voxel 2.00/2.03/2.00mm, field of view; right-left 224mm, anteroposterior 224mm and feet-head 120mm, voxel size; right-left 2mm, anteroposterior 2mm and slice thickness 2mm, reconstruction voxel size 1.75mm, gradient direction 32, b-value 1000mm/s and number of slices was 60 with total scan time 9:51 minutes.

Patients continued a followed-up schedule for 3 months, at the end of which the degree of physical dependence on exerting their ADL were assessed using the Modified Barthel Index (MBI) scale. Four patients dropped out the follow-up and the remaining 38 continued and accordingly they were divided to 3 groups; 11 moderately dependent patients attained ≤90 points (Group-I), 21 slightly dependent cases achieved 91-99 points (Group-II) and 6 independent patients scored 100 in MBI (Group-III). The MBI score was compared with the baseline assessed parameters to determine their values as prognostic biomarkers.

Statistical analysis was conducted using SPSS Prism, Version 20, 2013 created by IBM, Illinois, and Chicago, USA. Differences between the studied groups were tested using Chi-square, ANOVA and TUKEY'S tests. Correlation analysis was performed using Pearson's correlation test. p-value <0.05 was considered statistically significant.

Results

Baseline evaluation of the included 42 LIs patients showed that their mean age was 61.38±4.44 years, 22/42 (52.4%) were females, 20/42 (47.6%) were males, BMI was 31.07±2.7kg/m^2, the AADLs was 25.64±5.56 points, 19/42 (45.24%) were hypertensives, 12/42 (28.6%) were diabetics, 11/42 (26.2%) were smokers, 9/42 (21.4%) had dyslipi-

demia, 4/42 (9.5%) had ischemic heart diseases and 2/42 (4.8%) had atrial fibrillation. The mean CIMT was 1.22±0.34mm and the NIHSS was 14.1 ± 1.81 points. Thirty-six (85.7%) of the studied patients were pure motor and the remaining 6/42 (14.3%) were mixed sensorimotor LIs syndromes. Regarding the recent infarcts localization, 34/36 of pure motor and all sensorimotor LIs patients had infarctions in the posterior limb of the internal capsule with some thalamic extension in sensorimotor cases. Two of pure motor LIs patients had pontine infarctions. The lacunes' diameters were 9.34±2.03mm, the ARWMC score was 7.36 ±3.1 points and 14/42 (33.3%) had 1-3 old occult LIs.

The results of the present study showed that each of ipsilateral and contralateral FA were 0.296 ± 0.126 and 0.376±0.155 with FA ratio 0.83 ±0.098. At the same time, the ipsilateral and contralateral MD were 0.578 ±0.17 and 0.801 ±0.07 while the FN were 212.03 ±65.2 and 298.92 ±70.91 respectively.

The results showed that, the ages of the moderately and slightly dependent patients' groups were non-significantly different (p-value=0.226), but both groups were older than the independent group with p-values 0.003 and 0.038 respectively. The moderately dependent patients' group showed significant increase in the BMI, CIMT and existence of HTN than slightly dependent and independent patients' groups with p-values 0.05. At the same time, the moderately dependent group was significantly lower both other groups regarding the pre-stroke AADL score. On the other hand, the 3 studied groups showed non-significant difference regarding the NIHSS, patients' sex and lacunar diameters as well as the existence of DM, dyslipidemia and smoking Tables (1,2).

Regarding CS-DTT the 3 studied groups showed non-significant differences regarding the ipsilateral as well as contralateral FA, MD and FN with p-values 0.05. On the other hand, the FA ratio was significantly lower in moderately dependent than slightly dependent patients' groups (p-value 0.001) and both showed significantly reduced ratio compared to independent patients' groups with p-value 0.001 (Table 2), Figs. (1,2).

The present results stated that the MBI scale was negatively correlated with the patients' age, BMI, smoking index, ARWMC score, occult LIs number, CIMT, and lacunar infarction diameters with p-values 0.05. At the same time, MBI scale was positively correlated with each of AADLs and FA ratio (p-value 0.05). On the other hand, the MBI scale showed no correlation with the baseline NIHSS and each of ipsilateral as well as contralateral FA, MD and FN (Table 3), Fig. (3).

Table (1): Comparison between Group I (moderately dependent patients), Group II (slightly dependent) and Group III (independent) regarding the existence of some vascular risks of stroke.

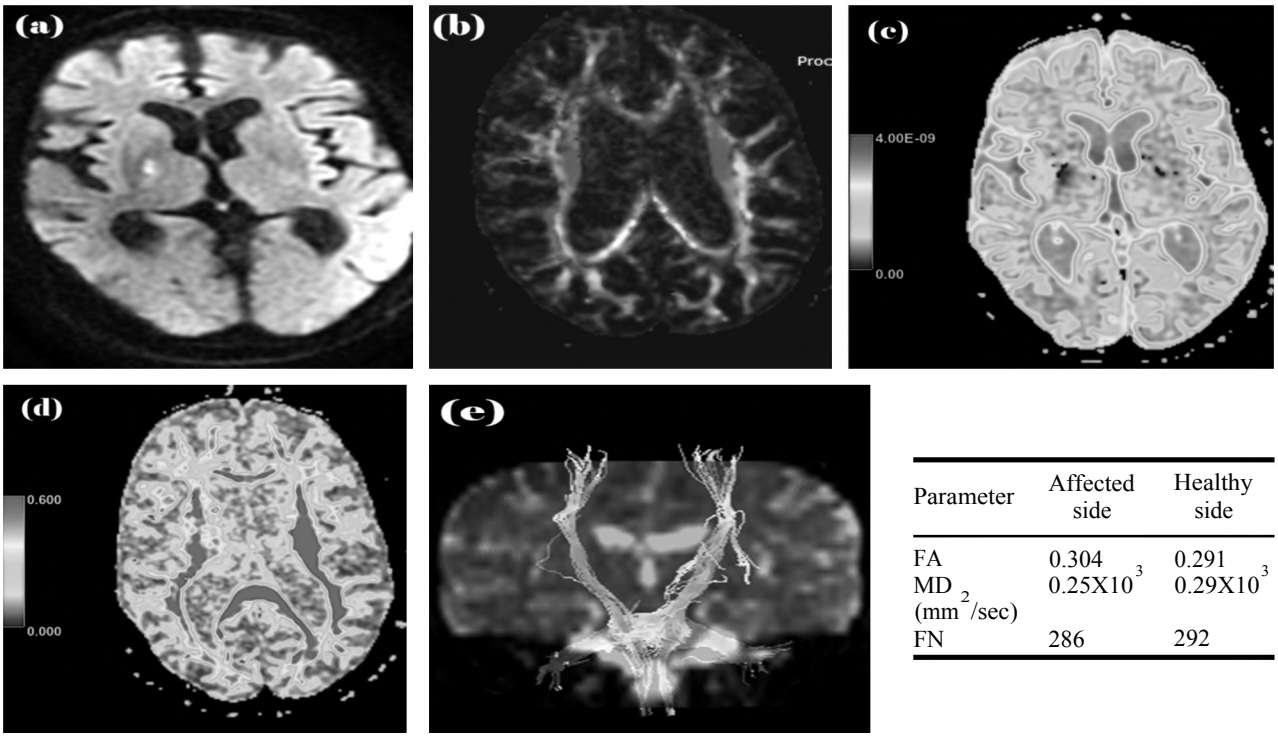
	Group I (n:11)	Group II (n:21)	Group III (n:6)	Total (n:38)	Chi-square	
					χ^2	p-value
Sex:						
Male	6 (55)	12 (57)	1 (17)	19 (50)	3.186	0.203
Female	5 (45)	9 (43)	5 (83)	19 (50)		
Hypertension:						
Present	8 (73)	9 (43)	0 (0.0)	17 (45)	8.373	0.015*
Absent	3 (27)	12 (57)	6 (100)	21 (55)		
Diabetes:						
Present	5 (45)	6 (29)	0 (0.0)	11 (29)	3.903	0.142
Absent	6 (55)	15 (71)	6 (100)	27 (71)		
Dyslipidemia:						
Present	3 (27)	5 (24)	0 (0.0)	8 (21)	1.952	0.377
Absent	8 (73)	16 (76)	6 (100)	30 (79)		
Smokers:						
Present	6 (55)	4 (19)	1 (17)	11 (19)	4.945	0.084
Absent	5 (45)	17 (81)	5 (83)	27 (71)		

*: Significant.

Table (2): Comparison between Group I (moderately dependent patients), Group II (slightly dependent) and Group III (independent) regarding the existence of some vascular risks of stroke.

	Group I (n:11)	Group II (n:21)	Group III (n:6)	ANOVA		TUKEY'S test		
				f-value	*p*-value	I vs. II	I vs. II	II vs. III
Age	63.5±3.2	61.0±4.4	56.3±3.3	6.404	0.004*	0.226	0.003*	0.038*
BMI	33.5±1.5	29.8±2.5	30.7±2.4	9.924	<0.001 *	<0.001 *	0.044*	0.694
ARWMC	11.2±1.7	6.5±2.0	3.8±0.8	39.116	<0.001 *	<0.001 *	<0.001 *	0.007*
Occult LBIs number	1.8±0.8	1.1±0.6	0.2±0.4	13.203	<0.001 *	0.012*	<0.001 *	0.009*
NIHSS	14.3±2.5	14.3±1.5	14.0±1.4	0.078	0.925			
AADLs	20.5±3.8	27.4±4.4	31.2±3.9	15.744	<0.001 *	<0.001 *	<0.001 *	0.133
Carotid IMT	1.6±0.2	1.1±0.3	0.9±0.2	24.038	<0.001 *	<0.001 *	<0.001 *	0.094
Lacunar diameter	9.9±2.8	9.1±1.9	8.8±1.2	0.718	0.495	–	–	–
Ipsilateral FA	0.32±0.14	0.28±0.12	0.32±0.14	0.492	0.616	–	–	–
Contralateral FA	0.47±0.17	0.35±0.14	0.32±0.14	2.919	0.067			
FA ratio	0.67±0.084	0.80±0.078	0.99±0.132	26.084	<0.001 *	0.001*	<0.001 *	<0.001 *
Ipsilateral MD	0.55±0.04	0.59±0.08	0.57±0.06	1.763	0.186	–	–	–
Contralateral MD	0.81±0.06	0.79±0.07	0.83±0.07	0.713	0.497	–	–	–
Ipsilateral FN	190±36.3	223±74	211±74	0.964	0.391	–	–	–
Contralateral FN	293±61	303±83	298±45	0.071	0.931	–	–	–
FN ratio	0.66±0.05	0.73±0.09	0.70±0.16	2.509	0.096			
MBI	82.0±3.0	94.3±2.6	100±0.0	125.063	<0.001 *	<0.001 *	<0.001 *	<0.001 *

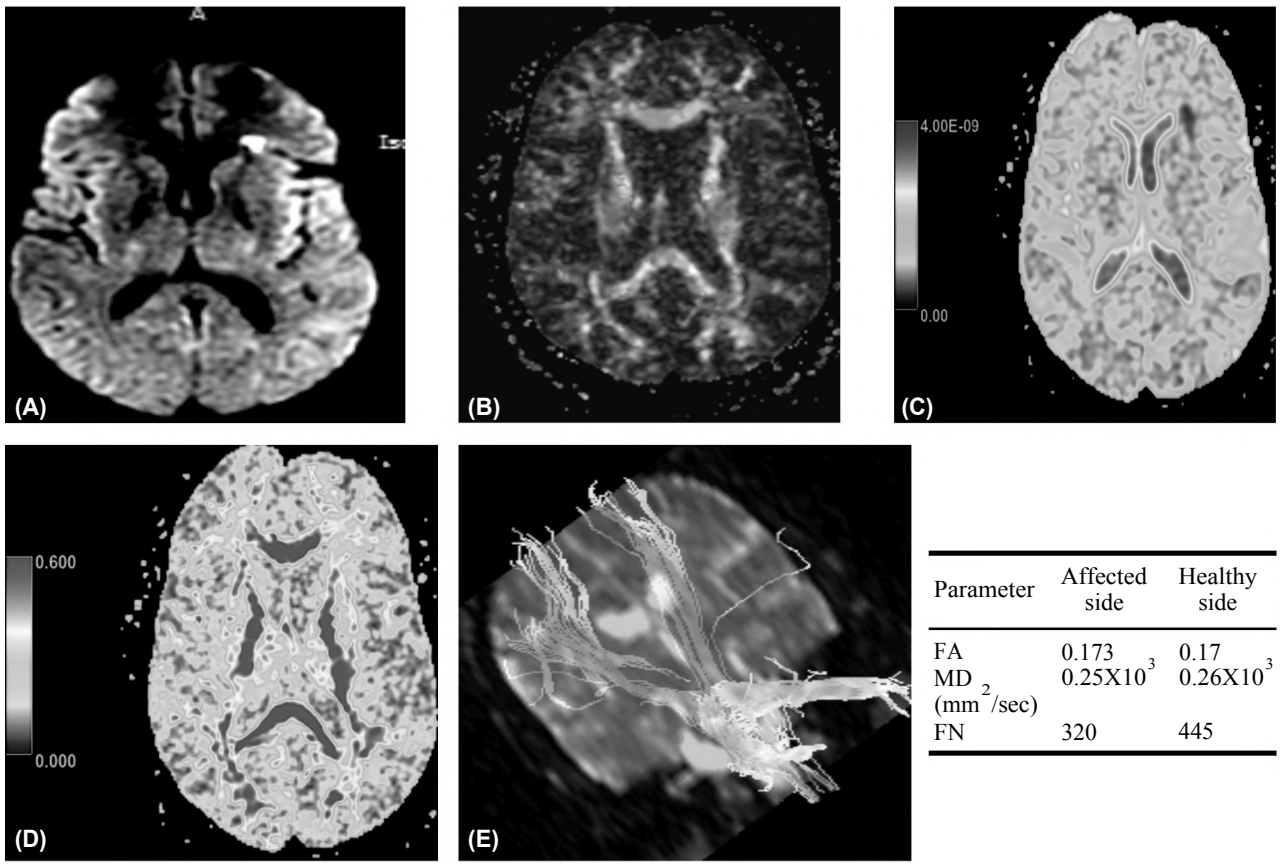
* : Significant.
AADLs : Advanced Activities of Daily Living Scale.
ARWMC : Age-Related White Matter Changes Scale.
BMI : Body Mass Index.
IMT : Intima Media Thickness.
FA : Fractional Anisotropy.
LBIs : Lacunar Brain Infarctions.
MBI : Modified Barthel Index.
MD : Mean Diffusivity.
FN : Fiber Number.
NIHSS : National Institute of Health Stroke Scale.



Parameter	Affected side	Healthy side
FA	0.304	0.291
MD (mm^2/sec)	$0.25X10^{-3}$	$0.29X10^{-3}$
FN	286	292

Fig. (1): An included 61-year-old male presented by left pure motor lacunar syndrome with admission NIHSS was 13 points and the 3-months MBI was 86 points (moderately dependent). The MRI images revealed (A) DWI showed lacunar infarction in the genu and posterior limb of the internal capsule, (B) The color-coded map showed normal CST (blue in color), (C) Decreased MD of the ipsilateral CST, (D) Increased FA at infarction site, and (E) Normal course and fiber number of the CST 3-d fiber tractography.

CST : Corticospinal Tract.
DWI: Diffusion Weighted Image.
FA: Fractional Anisotropy.
FN: Fiber Number.
MBI : Modified Barthel Index.
NIHSS: National Institute of Health Stroke Scale.



Parameter	Affected side	Healthy side
FA	0.173	0.17
MD (mm^2/sec)	$0.25X10^3$	$0.26X10^3$
FN	320	445

Fig. (2): An included fifty six years old female patient admitted with acute lacunar infarction at the left periventricular region with admission NIHSS was 13 points and the 3-months MBI was 88 points (moderately dependent). The MRI images revealed (A) DWI showed recent infarction at the left periventricular region, (B) The color-coded map showed mild distortion of left CST at the left periventricular region (blue in color), (C) Decreased MD of the ipsilateral CST, (D) Increased FA at infarction site and (E) Attenuated with decreased fibre number of left CST 3-d fiber tractography.

CST : Corticospinal Tract. FA: Fractional Anisotropy. MBI : Modified Barthel Index.
DWI: Diffusion Weighted Image. FN: Fiber Number. NIHSS: National Institute of Health Stroke Scale.

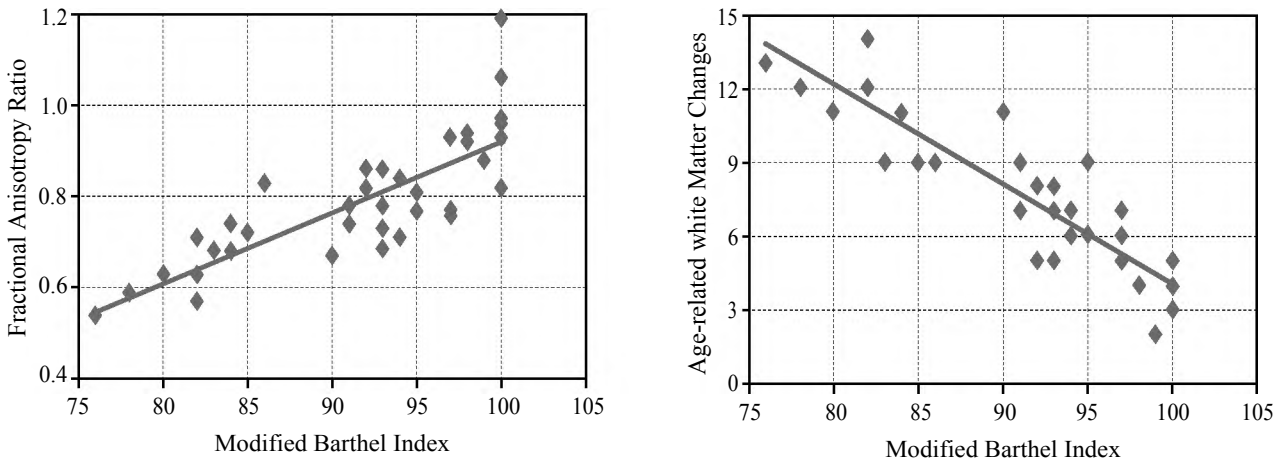


Fig. (3): The Modified Barthel index if positively correlated with fractional anisotropy ratio (Left) and negatively correlated with the age-related white matter changes scale (Right) among the studied lacunar infarction patients.

Table (3): Correlation of modified barthel index score in included lacunar infarction patients 3-months after stroke onset with other studied baseline parameters.

	Modified Barthel Index	
	r	*p*-value
Age	–0.572	<0.001*
BMI	–0.407	0.011*
ARWMC	–0.909	<0.001*
Occult LBIs	–0.722	<0.001*
NIHSS	–0.103	0.540
AADLs	0.692	<0.001*
Cartid IMT	–0.798	<0.001*
Lacunar diameter	–0.338	0.038*
Ipsilateral FA	0.140	0.403
Contralateral FA	–0.177	0.289
FA ratio	0.801	<0.001 *
Ipsilateral MD	0.234	0.158
Contralateral MD	0.099	0.553
Ipsilateral FN	0.197	0.235
Contralateral FN	0.095	0.570
FN ratio	0.238	0.150

* : Significant.
AADLs : Advanced Activities of Daily Living Scale.
ARWMC : Age-Related White Matter Changes Scale.
BMI : Body Mass Index.
IMT : Intima Media Thickness.
FA : Fractional Anisotropy.
LBIs : Lacunar Brain Infarctions.
MBI : Modified Barthel Index.
MD : Mean Diffusivity.
FN : Fiber Number.
NIHSS : National Institute of Health Stroke Scale.

Discussion

Lacunar strokes are small subcortical brain infarctions constituting about 25% of all ischemic strokes and despite their lower mortality rates, they result in moderately severe neurological deficit, increased disabilities and delayed recovery due to their deleterious effects on brain network circuits **[9]**. Accurate early prediction of the motor deficit after LIs is crucial to design suitable management and rehabilitation programs, minimizes neurological deficits and facilitates functional recovery. Tissue edema and mass effect may be responsible for increased motor deficit in early post-stroke period which makes reliability on clinically based biomarkers imprecise and need additional neuroimaging tools to assess corticospinal neurophysiological and structural integrity **[10]**.

The study showed that, symptomatic LIs were more common among elderly and old age was a bad prognostic factor associated with delayed and incomplete physical rehabilitations. These results are in accordance with the work of Torrealba-Acosta et al., 2018 **[11]** who found that advanced age is a non-modifiable risk factor for LIs associated with higher morbidity and mortality rates. On the other hand, these results are not in harmony with the work of Cai et al., 2016 **[12]** who concluded that the age per se is not a bad prognostic factor, but the age related vascular risks including hypertension, diabetes and cardiovascular diseases are the cause of LIs poor functional outcome. These results differences were possibly due to inclusion of many occult asymptomatic LIs patients in their studied cases.

The results also, declared that hypertension is associated with delayed recovery of LIs patients which is in accordance with the thesis of Fukui et al., **[13]** and Smith et al., 2017 **[14]** who specified that common vascular risks including hypertension is a poor prognostic factors in strokes of elderly. The results also, displayed that obesity and physical inactivity are common stroke risks and associated with significantly higher post-stroke disability in short-term LIs outcome which is passing with the work of Howard and McDonnell, 2015 **[15]** who declared that healthy life-style, weight control and regular exercises are well documented modifiable risk factors associated with good prognosis after LIs through accompanied consumption of healthy diets, weight control and better vascular risks control (hypertension, DM and smoking).

The study also showed that, increased CIMT is associated with poorer prognosis and lesser functional outcome. These results agree with the work of Song et al., 2018 **[16]** who declared that increased CIMT was an independent risk of LIs and associated with poorer outcome due to its high association with vascular risks and increased tissue inflammatory markers. On the contrary, Polak and O'Leary, 2016 **[17]** stated that increased CIMT may not associated with higher LIs induced motor disability as it is more related to large vessel atherosclerosis than Small Vessel Disease (SVD). At the same time, the present study stated that the presence of occult SVD imaging markers as WMHs and occult LIs are associated with higher motor disabilities after symptomatic LIs which is in agreement with the work of El-Senousy et al., 2013 **[18]** and Ferguson et al., 2018 **[19]** who concluded that, the presence of covert SVD especially leukoaraiosis is associated with poor functional and cognitive outcome after symptomatic stroke.

Diffusion tensor imaging is a technique that enables quantitative estimation of tissue microstructure based on diffusivity properties of Brownian water molecules motions which makes it able to reconstruct a 3D macroscopic orientation and visualize the white matter tracts integrity within

the infarcted area and thus anticipate the degree of recovery **[20]** . The study showed that decreased ipsilateral/contralateral FA ratio of CS-DTT was an early sensitive biomarker predicting post-stroke functional outcome and motor disability after motor and sensorimotor LIs. At the same time, early assessed ipsilateral and contralateral FA, MD and FN showed non-significant differences between dependent and independent patients' groups possibly due to their wide range of normality resulted in statistically non-significant differences and their need of longer durations to show significantly reliable changes. These results are in accordance with the work of Elkholy et al., 2015 **[21]** who concluded that reduced early post-stroke FA ratio is an indicator of irreversible tissue damage and more sensitive than the clinically based NIHSS as the latter may be elevated by the tissue edema and mass effect rather than axonal damage, but their study differed from the present one in DTI procedure timing (1-week after stroke onset) and inclusion of patients with widely different NIHSS range. These differences resulted in recording a reduced ipsilateral FA in the dependent than independent patients' groups. In a parallel way, the present results were in harmony with the work of Alegiani et al., 2017 **[22]** who reported non-significant changes in early ipsilateral FA between dependent and independent patients' groups due to its diverse changes which was decreased in a sector of patients and increased in another. On the other hand, Puig et al., 2013 **[23]** stated that early FA increase is a surrogate marker of motor deficit after stroke and they did not report significant reduction of FA ratio at 12 hours and 7 days assessment which became significantly reduced in the 30th day post-stroke DTI assessment. The latter was an important independent predictor of long-term motor outcome after occlusive stroke. The cause of these differences is the heterogeneity of their included patients with large and small arteries infarctions, had non-motor lacunar syndromes and received intravenous thrombolysis who were in the exclusion criteria of the present study. In contrast to the results of this study, the work of Abdeldayem et al., 2017 **[24]** delineated the presence of significant decrease in FA and pyramidal tract FN inside the infarcted area possibly due to undergoing the DTI after 2 weeks from stroke onset at which the infarction showed subacute changes.

Limitations:

The short-term period of follow-up and the need of post-stroke cognitive impairment assessment. Non-inclusion of pure sensory, ataxic hemiparesis and dysarthria clumsy hand lacunar syndromes as the localizations of their lesions are away from the examined CS-DTT.

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التنبؤ المبكر للآثار الوظيفية لجلطات الشرايين المخية الدقيقة بإستخدام تصوير الرنين المغناطيسى الإنتشارى لتتبع المسارات العصبية

تعتبر السكتة الدماغية الوعائية حلقة من الإختلال العصبى الناجم عن الجلطة المخية البؤرية أو العمود الفقرى أو جلطة الشبكية. وقد قسمت السكتات الدماغية الإقفارية إلى ٥ أنواع فرعية.

تحدث جلطات الشرايين المخية الدقيقة نتيجة إنسداد الشرايين الصغيرة والتى يتراوح قطرها من ٠.٥ إلى ١٥ملم. وقد تكون هذه الجلطات عديمة الأعراض ولكن الأعراض تظهر فى حوالى ٢٥٪ من الحالات. ومن أشهر الأعراض التى تظهر على مرضى الجلطات حدوث شلل أو ضعف فى الجانب الحركى لإحدى شقى الجسم أو فقد الإحساس أو صعوبة النطق.

على الرغم من تحسن العلاج، فإن معظم المرضى يعانون من العجز الحركى بعد السكتة الدماغية، وغالبا ما تسبب الإعاقة. ومن شأن التنبؤ المبكر للتحسن أن يساعد على ترشيد أهداف التأهيل.

تعتبر القناة القشرية النخاعية هى المسار الرئيسى الذى يتوسط الحركات الإرادية، وقد أثبت التصوير العصبى والهيكلى أن حركة المريض تعتمد إعتمادا كبيرا على سلامة الألياف الحركية.

يلعب التصوير بالرنين المغناطيسى دورا بارزا على نحو متزايد ليس فقط فى تحديد الإصابات الدماغية، ولكن أيضا فى تحديد العلاقة بين تلك الإصابات والتغيرات التشريحية والوظيفية الدماغ.

هناك طرق حديثة تم تطويرها التى لم تدخل بعد المجال الإكلينيكى الروتينى. التصوير بالرنين المغناطيسى الإنتشارى وتتبع المسارات العصبية هو واحد من هذه الوسائل الحديثة والذى ينظر على وجه التحديد فى إتجاه وسلامة الألياف العصبية وكيف أنها تتغير فى حالة الإصابة العصبية بسبب أسباب مختلفة منها السكتة الدماغية.