Alsiddig and Ali *Artery Research* 2024, **30**:1
https://doi.org/10.1007/s44200-024-00044-w

Artery Research

RESEARCH ARTICLE

Open Access

Effects of Smoking on Intima-Media Thickness of the Common Carotid Artery Using Ultrasonography

Asmaa Mustafa Alsiddig[1] and Ibrahim Abdelrhim Ali[2*]

Abstract

Background Cigarette smoking is a causative factor in premature atherosclerosis, but the exact mechanism of smoking-induced damage to the arterial wall and its relationship to the atherosclerotic process are still largely unknown. Carotid ultrasound may help target treatment. The aim of this study was to measure carotid intima-media thickness (IMT) and carotid Doppler parameters in Sudanese smokers compared to non-smokers using ultrasound.

Methods This was a retrospective, case–control, community-based study conducted between June 2021 and September 2021. The study was conducted on 100 Sudanese subjects (50 smokers as the case group and 50 non-smokers as the control group). The practical part was conducted in Khartoum State at Al Raqi University Hospital using the E-CUBE 8-ALPINION and at Yastbshroon Hospital using the Fukuda Denshi Sefius UF890AG with a high-frequency linear transducer (7–10 MHz). Scanning was performed in the supine position with the neck extended. Pulsed-wave (PW) Doppler spectral and IMT measurements were obtained.

Results The mean age was 29.8 ± 4.5 years (range 24–40 years), and the mean IMT in smokers was 0.6 ± 0.06 mm, which was greater than the mean in non-smokers (0.462 ± 0.09 mm) ($p = 0.000$). Peak systolic velocity (PSV) was increased in smokers (40.0 ± 5.67 cm/s) compared to non-smokers (26.5 ± 5.6 cm/s) ($p = 0.000$), and end-diastolic velocity (EDV) was decreased in smokers (6.0 ± 1.2 cm/s) compared to non-smokers (9.8 ± 2.2 cm/s) ($p = 0.000$). In addition, the resistive index (RI) and the systolic-diastolic ratio (S/D) were not significantly different between smokers and non-smokers. The study showed that there was a significant positive correlation between IMT and the number of cigarettes per day in chronic smokers ($p < 0.05$), whereas peak systolic velocity (PSV) and end-diastolic velocity (EDV) were not affected in chronic smokers.

Conclusions There was a statistically insignificant difference between the case (smokers) and control (non-smokers) groups in terms of age, body mass index (BMI), resistance index (RI), and systolic–diastolic ratio (S/D). While there were statistically significant differences in intima-media thickness (IMT), peak systolic velocity (PSV), and end-diastolic velocity (EDV), regular follow-up of individuals with a history of smoking is recommended to detect carotid intimal changes earlier.

Keywords Smoking, Pulsed wave (PW), Mean intima-media thickness (IMT), Systolic velocity (PSV), End diastolic velocity (EDV), Resistive index (RI), Systolic–diastolic ratio (S/D)

*Correspondence:
Ibrahim Abdelrhim Ali
hemamedicine@gmail.com
Full list of author information is available at the end of the article

1 Background

Cigarette smoking remains one of the leading preventable causes of cardiovascular disease [1]. When a person inhales a cigarette, their heart rate becomes faster than normal. This causes the blood vessels in the body to constrict, damaging the inner lining of the arteries, vessels, and veins that carry blood around the body. This damage can slow blood flow on its own, but combined with other problems such as atherosclerosis, it is associated with an increased risk of cardiovascular events such as heart attack and stroke, the two leading causes of death in the developed world [2].

Cigarette smoking is a well-established risk factor for coronary heart disease, peripheral vascular disease, and stroke. One possible explanation for this association is that smoking increases the formation of atherosclerosis. Indeed, chronic cigarette smoking has been associated with an increased risk of atherosclerotic disease of the coronary, aortic, abdominal, and peripheral arteries and, more recently, of the extracranial carotid arteries [3].

Cigarette smoking is a causative factor in premature atherosclerosis, but the exact mechanism of smoking-induced damage to the arterial wall and its relationship to the atherosclerotic process are still largely unknown. The adverse effects of smoking on vascular wall structure have traditionally been assessed by autopsy studies. Clinically applicable diagnostic measures such as ultrasound imaging have been widely used in recent years [4].

Arterial stiffness is now considered an increasingly important biomarker in cardiovascular risk assessment and in the detection of incipient vascular disease [5].

The most widely used surrogate for aortic pulse wave velocity (PWV) is carotid-femoral PWV, where transit times are assessed from the signal measured at the carotid and femoral arteries. These sites provide superficial arteries that are still relatively close to the aorta [6].

Measurement of the combined intima-media layer of the common carotid artery (CCA) using high-resolution brightness mode (B-mode) ultrasound is now widely recognized as a useful tool for the early detection of subclinical cardiovascular disease (CVD) and ischaemic brain disease [3]. The assessment of intima-media thickness (IMT) can identify individuals at risk of future cardiovascular events and also assess the effectiveness of different therapeutic modalities in controlling morbidities leading to the development of atherosclerotic disease by identifying the regression of IMT values after such intervention [3].

In addition, the IMT of CCAs is a useful parameter for detecting the early development of atherosclerosis [7, 8] and has become an important predictor of morbidity and mortality from cardiovascular disease [7–11].

The B-mode ultrasound image of a normal carotid artery is characterized by two parallel echogenic lines separated by an echo-lucent (hypoechoic) space. The parallel echoes correspond to the adventitial and intimal layers of the arterial wall, and the intervening echo-lucent region represents the media, although there may be systemic discrepancies between sonographic and histological measurements of intimal and medial thickness [12]. Changes in arterial wall thickness indicate structural arterial changes resulting from arterial remodeling, most commonly due to the atherosclerotic process. CCA-IMT has traditionally been used as a marker of subclinical atherosclerosis, although important limitations of this marker have been recognized [12].

A study was carried out to determine the effect of acute, chronic, and passive smoking on arterial stiffness and found that acute, chronic, and passive smoking all has a detrimental effect on arterial stiffness, although the role of chronic smoking in increasing arterial stiffness is somewhat more controversial. Chronic smoking has also been shown to play a role in sensitizing the arterial response to acute smoking [2].

Another study comparing the acute and chronic effects of smoking on large artery characteristics showed that at baseline, the augmentation index (AIx) was significantly higher in smokers compared with non-smokers. Although PWV was higher in smokers than in non-smokers, the difference was not statistically significant [13].

The aim of this study was to investigate the changes that occur in CCA-IMT in relation to smoking duration and the number of cigarettes consumed per day in current Sudanese smokers compared to non-smokers.

2 Materials and Methods

This study was a descriptive, community-based, retrospective, case–control study conducted at Al-Raqi University Hospital and Yastbshroon Hospital from June 2021 to October 2021.

The objectives of the study were explained to all study participants. Informed consent was obtained from each study participant before the start of the examination. The sample size was calculated using online sample size collection software (https://www.openepi.com/SampleSize/SSCC.htm). To detect a difference of 0.5 SD between the means of the two groups, the baseline mean of left and right IMT was 0.4 ± 0.06 in the control group. Therefore, it was important to recruited 50 patients in each group, so the study included 100 participants, with 50 current smokers (as cases) and 50 non-smokers (as controls) of the same age group, sex, and BMI.

2.1 Study Populations

Chronic smoking and never-smoking subjects.

Fig. 1 The FUKUDA DENSHI Sefius UF-890AG

Fig. 2 E-CUBE-ALPINION high-frequency ultrasound devices

2.2 Inclusion Criteria

Healthy people over the age of 24 and under the age of 40 with a normal body mass index (BMI) between 18.5 and 24.9 were included in the study.

2.3 Exclusion Criteria

Subjects less than 24 years of age and more than 40 years of age.

Subjects having any medical condition like HTN, DM, endocrine disorders, cardiovascular disorders or any other disorders.

Patients with systematic diseases such as head injuries, cancer, congestive heart failure, myocardial infarction, and chronic renal diseases.

Also subjects with BMI less than 18.5 or more than 24.9.

2.4 Data Collection Instruments

Data were collected using data collection sheets designed to include all study variables, including carotid intima-media thickness, age, height, weight, sex, peak systolic velocity, end-diastolic velocity, resistance index, systolic–diastolic ratio, and number of cigarettes smoked per day.

2.5 Physical Examination

Weight, height, BMI, and blood pressure were calculated using standard techniques.

2.5.1 Equipment of the Study

The equipment required for carotid ultrasound included an ultrasound machine with Doppler capability, a linear ultrasound probe and gel.

The ultrasound examination was performed with a real-time scanner using the FUKUDA DENSHI Sefius UF-890AG (Fig. 1) and E-CUBE-ALPINION high-frequency ultrasound devices (Fig. 2).

2.5.2 Carotid Doppler Ultrasonography

2.5.2.1 Patient Position The patient lies in the supine or semi-supine position with the head slightly elevated and rotated 45 degrees away from the side to be examined, and the examiner sits close to the patient's head. The patient's head has been tilted away from the side to be examined to facilitate exposure of the neck [14].

2.5.2.2 Scanning Technique The common carotid arteries were imaged bilaterally using high-frequency pulse-wave Doppler ultrasound with a linear array transducer (7–10 MHz). With the transducer tilted cephalically at the level of the mandible and caudally in the supraclavicular region, each common carotid artery (CCA) was scanned as completely as possible in longitudinal view using multiple anterior, lateral, or posterolateral probe techniques to obtain the best possible image of the vessels.

The mid-CCA blood flow velocity was assessed using pulsed wave (PW) Doppler spectral analysis (see Fig. 3). As this section of the vessel is well identified, all measurements were taken from the CCA immediately anterior to the bifurcation to the ICA and external carotid artery (ECA) [15].

2.5.2.3 Doppler Measurements Peak systolic velocity, end-diastolic velocity, and systolic/diastolic ratio are used to determine the pattern of blood flow in the common carotid artery (Fig. 4)

The resistive index (RI) is one of the most commonly used vascular ultrasound indices because of its simplicity. The RI is proportional not only to vascular resistance but also to vascular compliance. As a vessel narrows and resistance to flow increases, the RI increases.

As the study of the vasculature is affected by cardiac activity, the operator ensured that all participants did not engage in any physical activity before the study that would affect the readings. To optimize the most reliable results, adjustments were made to the size of the gate or sample volume. The Doppler sample volume refers to the frequency spectrum from a specific location. The sample volume or gate should fill the vessel lumen without touching the vessel walls (~ 2/3 of the vessel diameter). Increasing the sample volume will capture more slow-flow components near the walls, resulting in a noisy frequency shift spectrum and blurring of the spectral Doppler plot. The Doppler angle can also be adjusted using the switch on the instrument panel. Velocity measurements are only reliable when the Doppler angle is < 60°.

2.5.3 B-mode Ultrasonography

IMT was measured by B-mode ultrasound of the bilateral CCAs using a high-resolution ultrasound machine with a high-frequency linear probe.

The B-mode ultrasound image of a normal carotid artery is characterized by two parallel echogenic lines produced by the lumen-intima and media-adventitial interfaces seen at the level of the arterial wall, separated by an anechoic cavity (echo-lucent or hypoechoic space). The thickness of the intima-media complex is indicated by the distance between these two lines. An approximately 1 cm section of the carotid bulb from the plaque-free segment was used for IMT assessment of the common and carotid arteries.

IMT was measured on a two-dimensional (2D) grey-scale image. The optimal grey-scale image of the longitudinal scan of the carotid artery, passing through the center of the carotid artery, shows two bright interfaces along the arterial wall. On the far wall, the upper bright line is the blood–intima interface, and the lower bright line is the media-adventitia interface. There is no

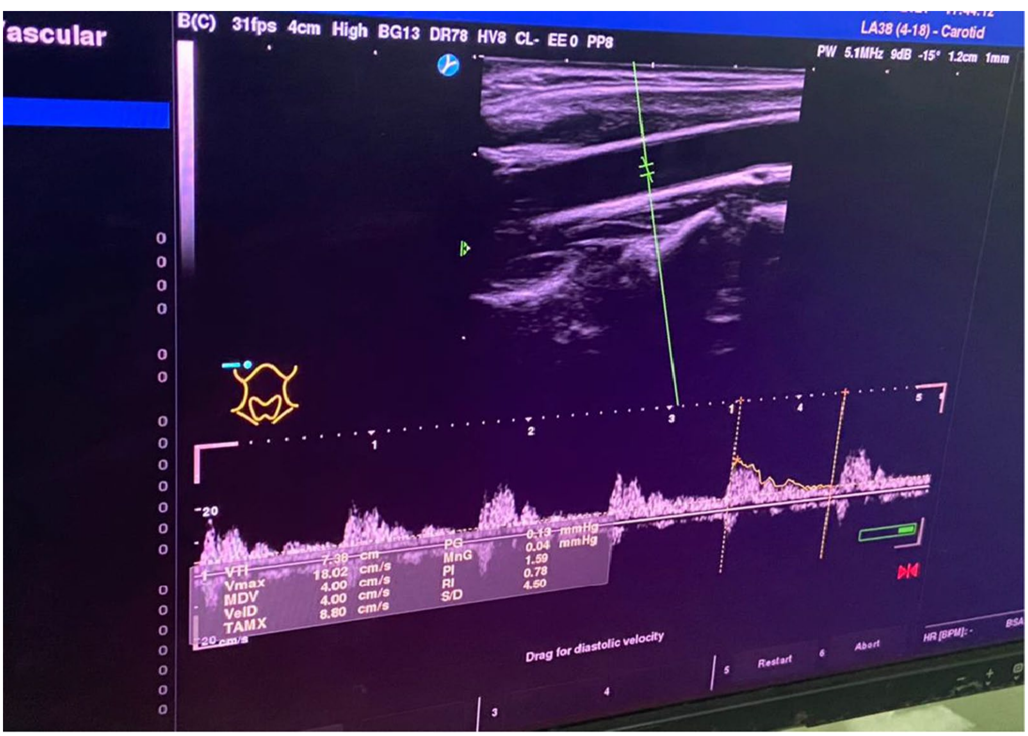

Fig. 3 Spectral ultrasound of the common carotid artery shows the Doppler parameters PSV = 18.02, EDV = 4, RI = 0.78 and S/D = 4.50

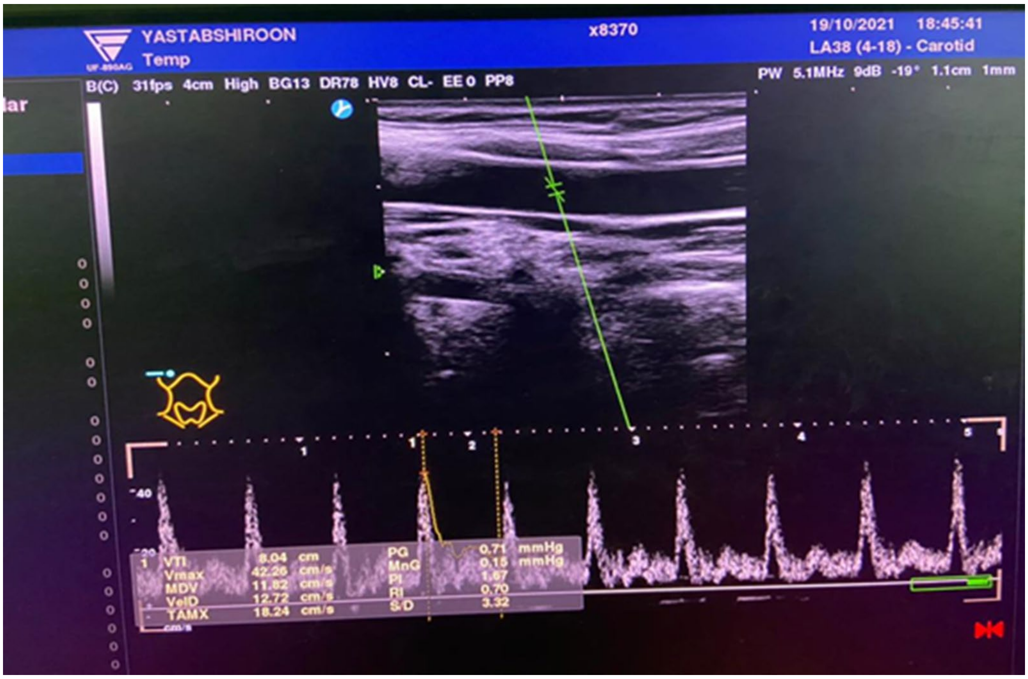

Fig. 4 Spectral ultrasound of the common carotid artery shows the Doppler parameters PSV = 42.26, EDV = 12.72, RI = 0.70 and S/D = 3.32

interface between the intima and the media. The distance between the upper and lower light lines represents the thickness of the intima and media layers.

IMT values were then determined manually. The methods for this prospective study were performed by a licensed sonographer, and the protocols were approved by two radiologists (Fig. 5)

2.5.4 Image Interpretations

The photograph was labeled with the patient's name, the department, the date of the examination, and the side of the anatomical region examined. Every patient involved in this study was assured of privacy and confidentiality; no patient information was shared, and every patient received the same level of care.

2.6 Data Analysis and Presentation

The data were analyzed using SPSS (Statistical Package for Social Science). The analyzed data are presented in the form of tables and figures. Data were analyzed using IBM SPSS Statistics, version 21.0 (IBM Corp., Armonk, NY, USA). Quantitative variables were expressed as mean ± standard deviation (SD), and the normality of the data distribution was tested using the Kolmogorov–Smirnov test. Qualitative data were presented as frequencies and proportions.

The independent sample t test was used to compare the means of variables between smokers and non-smokers. Pearson's correlation was also used to analyses correlations between continuous variables. p values < 0.05 were considered statistically significant.

2.7 Ethical Considerations

Written informed consent was obtained from all participants. The study was approved by the scientific and ethical committee of the University of Medical Sciences and Technology (UMST). The objectives of the study were explained to all participants. Informed consent was obtained from each study participant before the start of the examination.

3 Results

3.1 Demographic Data

The mean age was 29.8 ± 4.5 years, and the most common age group for both smokers and non-smokers was 24–28 years. The mean BMI was 22.92 (Table 1, Fig. 6) regarding gender, the participants were equally divided between males (50.0%) and females (50.0%). Thirty-three (66.0%) of the smokers smoked 6–10 cigarettes per day.

The mean blood pressure in smokers was (115.65 ± 3.59/76.60 ± 1.48) mm/hg while the mean blood pressure in non-smokers was (116.16 ± 2.92/76.54 ± 1.80) mm/hg. There was no statistically significant difference between smokers and non-smokers regarding systolic and diastolic blood pressure ($p > 0.05$). (Table 1).

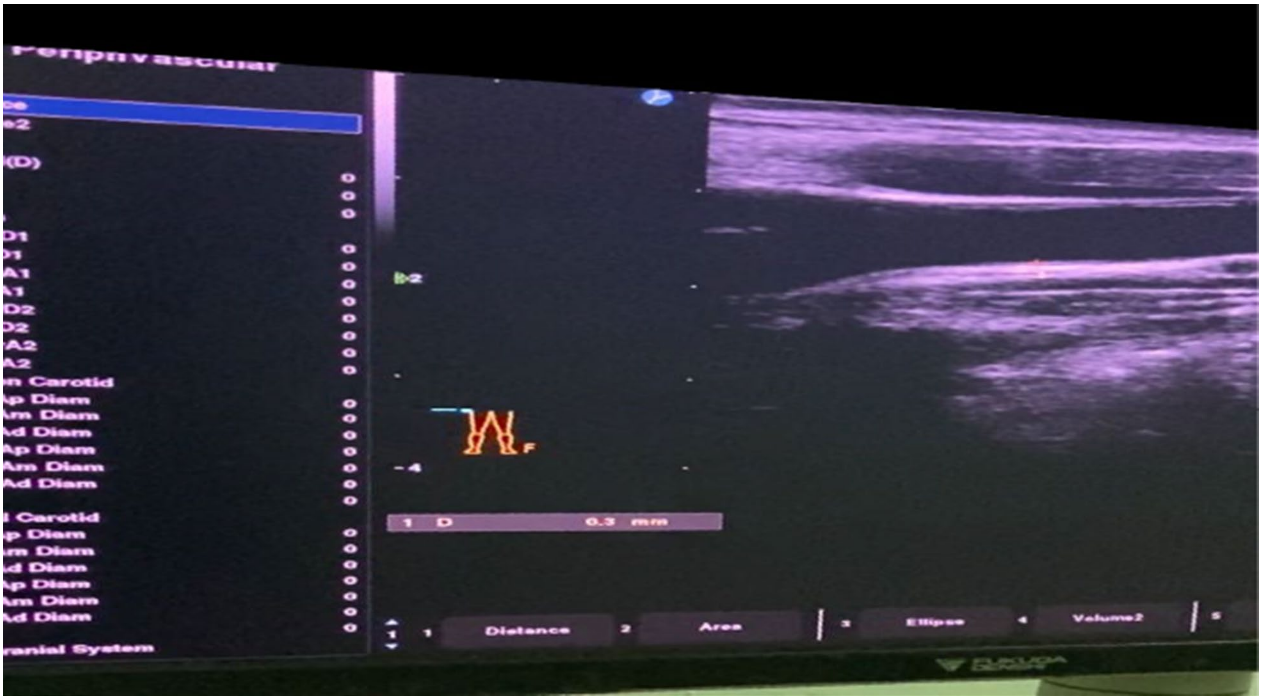

Fig. 5 B-mode ultrasound of the common carotid artery shows the IMT with a value = 0.3 mm

Table 1 Descriptive statistics of age, BMI, and blood pressure in smokers and non-smokers ($n = 100$)

Variables	Smokers				Nonsmokers				*t* test
	Mean	SD	Min	Max	Mean	SD	Min	Max	*p* value
Age	29.840	4.577	24	40.0	29.820	5.150	24	40.0	0.753
BMI	22.928	1.387	20.2	24.90	22.575	1.717	18.40	25.0	0.459
Systolic blood pressure (SBP), mmHg	115.65	3.59	108.71	119.55	116.16	2.92	111.60	119.70	0.441
Diastolic blood pressure (DBP), mmHg	76.60	1.48	74.05	79.04	76.54	1.80	73.61	79.11	0.849

3.2 Ultrasound Parameters Measurements

The mean right IMT was 0.66 mm in smokers and 0.46 mm in non-smokers. The mean left IMT was 0.65 mm in smokers and 0.46 mm in non-smokers (Table 2).

The mean of Doppler measurements of the right PSV was (26.5) ± 5.4 cm/s in smokers and (39.9) ± 5.6 cm/s in non-smokers. The mean of Doppler measurements of left PSV was (26.5) ± 5.4 cm/s in smokers and (39.9) ± 5.6 cm/s in non-smokers.

The mean of right EDV Doppler measurements was (6.0) ± 1.2 cm/s in smokers and (9.8) ± 2.2 cm/s in non-smokers. The mean of the Doppler measurements of the left EDV was (6.0) ± 1.2 cm/s in smokers and (9.8) ± 2.2 cm/s in non-smokers.

An independent sample *t* test shows that the mean of right and left IMT, PSV, and EDV in smokers and non-smokers is significantly different, while the right and left RI and SD are not significantly different, and the correlation is significant at the 0.05 level (two-tailed) (Table 2).

The two means of IMT are considered significantly different at the 95% confidence level ($p = 0.00$; $p < 0.05$), indicating that the mean in smokers is significantly higher than the mean in non-smokers. (Table 2).

3.3 Carotid Measurements and Gender

Gender was found to affect EDV only in the right and left carotid arteries. EDV was found to be slightly lower in females compared to males (Table 3).

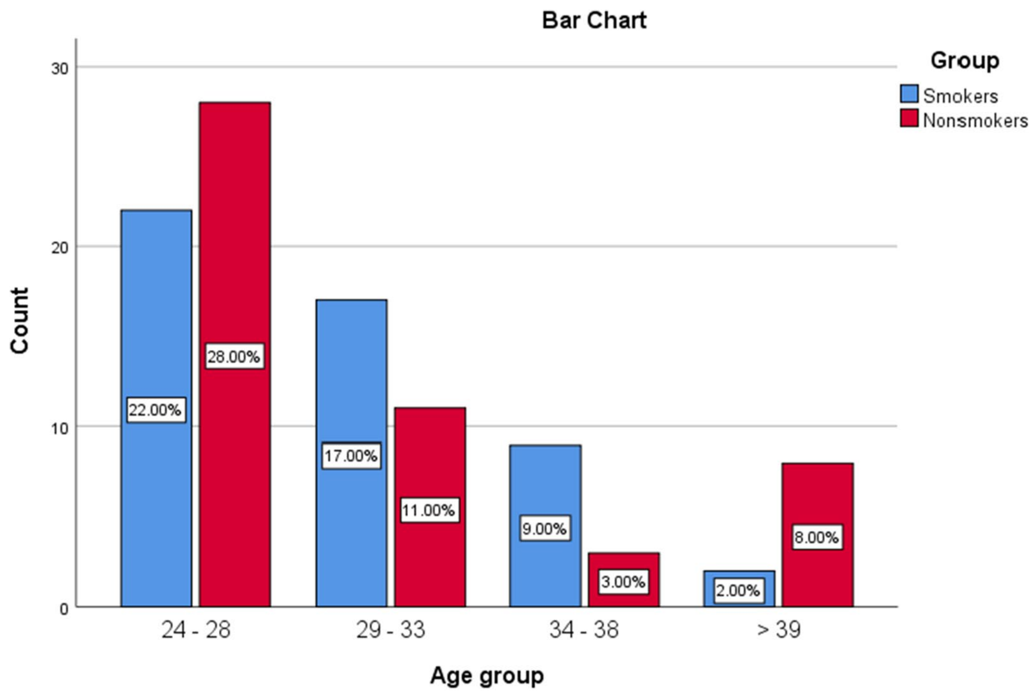

Fig. 6 Frequency distribution of gender of among smokers and non-smokers of a selected population at Khartoum 2021 ($n = 100$)

Table 2 Descriptive statistics of, IMT, and Doppler parameters measurements in smokers and non-smokers ($n = 100$)

Variables		Smokers				Nonsmokers				*t* test
		Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	***p* value**
IMT, mm	Right	0.660	0.061	0.5	0.70	0.462	0.090	0.30	0.70	0.000
	Left	0.658	0.061	0.5	0.70	0.462	0.090	0.30	0.70	0.000
PSV, cm s^{-1}	Right	26.539	5.474	18.02	36.31	39.986	5.671	29.0	47.900	0.000
	Left	26.559	5.495	18.02	36.310	39.984	5.669	29.00	47.900	0.000
EDV, cm s^{-1}	Right	6.035	1.211	4.0	8.590	9.821	2.289	5.90	13.400	0.000
	Left	6.028	1.213	4.00	8.590	9.821	2.289	5.90	13.400	0.000
RI	Right	0.766	0.048	0.67	0.880	0.755	0.044	0.66	0.830	0.212
	Left	0.766	0.048	0.67	0.880	0.754	0.044	0.66	0.830	0.214
S/D	Right	4.508	1.174	3.06	8.260	4.213	0.786	2.99	6.020	0.143
	Left	4.513	1.184	3.06	8.260	4.213	0.786	2.99	6.020	0.139

3.4 Carotid Measurements and Age of Smokers

An ANOVA test comparing the means of IMT, PSV, and EDV in different age groups of smokers showed significant mean differences between IMT, PSV, and age of smokers, while there was a non-significant negative mean between EDV and age of smokers. The mean is significant at the 0.05 level (two-tailed). (Table 4).

3.5 Carotid Measurements and Number of Cigarettes Per Day

ANOVA test comparing the mean of IMT, PSV, and EDV with the number of cigarettes smoked per day among smokers showed a significant mean differences between right and left IMT, PSV, and number of cigarettes and a non-significant negative mean between right and left

Table 3 Mean right and left IMT and Doppler parameters measurements in both genders in smokers ($n = 100$)

Variables		Gender	*N*	Mean	Std. deviation	Std. error mean	*p* value
Right	IMT, mm	Male	25	0.656	0.0583	0.0117	0.646
		Female	25	0.664	0.0638	0.0128	
	PSV cm s^{-1}	Male	25	26.942	5.32181	1.06436	0.607
		Female	25	26.135	5.70247	1.14049	
	EDV cm s^{-1}	Male	25	6.366	1.28253	0.25651	0.052
		Female	25	5.703	1.05963	0.21193	
	RI	Male	25	0.7584	0.04279	0.00856	0.257
		Female	25	0.7740	0.05276	0.01055	
	S/D	Male	25	4.317	1.03480	0.20696	0.253
		Female	25	4.699	1.29037	0.25807	
Left	IMT, mm	Male	25	0.652	0.0586	0.0117	0.492
		Female	25	0.664	0.0638	0.0128	
	PSV, cm s^{-1}	Male	25	26.942	5.32174	1.06435	0.627
		Female	25	26.175	5.74625	1.14925	
	EDV cm s^{-1}	Male	25	6.366	1.28253	0.25651	0.047
		Female	25	5.689	1.05859	0.21172	
	RI	Male	25	0.7580	0.04320	0.00864	0.247
		Female	25	0.7740	0.05276	0.01055	
	S/D	Male	25	4.317	1.03480	0.20696	0.246
		Female	25	4.708	1.30744	0.26149	

Person chi square test shows insignificant different in mean of Doppler parameters between female and males' smokers, the mean is significant at the 0.05 level (2-tailed)

Table 4 Mean and ANOVA test of the right and left IMT and Doppler parameters with different age group among smokers ($n = 100$)

Age group		Right carotid			Left carotid		
		IMT	PSV	EDV	IMT	PSV	EDV
24–28	Mean	0.632	25.973	6.348	0.632	26.018	6.348
	SD	0.072	5.353	1.185	0.072	5.407	1.185
29–33	Mean	0.682	26.157	5.723	0.676	26.157	5.702
	SD	0.039	5.810	1.172	0.044	5.810	1.171
34–38	Mean	0.678	26.828	5.951	0.678	26.827	5.951
	SD	0.044	4.777	1.424	0.044	4.777	1.424
39–40	Mean	0.700	34.715	5.620	0.700	34.715	5.620
	SD	0.000	0.092	0.170	0.000	0.092	0.170
ANOVA	*p* value	0.006	0.04	0.06	0.007	0.04	0.06

EDV and number of cigarettes; the correlation is significant at the 0.05 level (two-tailed) (Table 5).

3.6 Carotid Measurements and Blood Pressure

No correlation was reported between SBP and DBP with right and left IMT and Doppler parameters. There was significant positive correlation between systolic blood pressure and age ($r = 0.455$, $p < 0.001$), weight ($r = 0.660$, $p < 0.001$) and BMI ($r = 0.278$, $p = 0.005$). There was significant positive correlation between diastolic blood pressure and age ($r = 0.640$, $p < 0.001$), weight ($r = 0.683$, $p < 0.001$) and BMI ($r = 0.228$, $p = 0.023$) (Table 6).

4 Discussion

This was a descriptive, retrospective, case–control, community-based study conducted to assess common carotid artery intima-media thickness and Doppler parameters by ultrasound. According to the age groups of the study population, the highest frequency

Table 5 Mean and ANOVA test of the right and left IMT and Doppler parameters with number of cigarettes smoked per days among smokers (*n* = 100)

No of cigarettes/day	*N* (%)	Mean ± SD	Right			Left		
			IMT	PSV	EDV	IMT	PSV	EDV
1–5	15 (30%)	Mean	0.587	23.870	6.583	0.587	23.869	6.583
		SD	0.052	4.122	0.823	0.052	4.121	0.823
6–10	33 (66%)	Mean	0.691	27.358	5.906	0.688	27.388	5.895
		SD	0.029	5.636	1.245	0.033	5.663	1.246
11–15	2 (4%)	Mean	0.700	33.045	4.065	0.700	33.045	4.065
		SD	0.000	0.573	0.078	0.000	0.573	0.078
ANOVA		*p* value	0.001	0.025	0.10	0.001	0.025	0.10

Table 6 Correlation between systolic blood pressure and different studied variables (*n* = 100)

Variable	SBP (mmHg)		DBP (mmHg)	
	Pearson correlation	*p* value	Pearson correlation	*p* value
Age	0.455	**< 0.001**	0.640	**< 0.001**
Weight	0.660	**< 0.001**	0.683	**< 0.001**
BMI	0.278	**0.005**	0.228	**0.023**
RT IMT	0.027	0.787	0.113	0.261
RT PSV	0.040	0.693	− 0.057	0.570
RT EDV	0.015	0.885	− 0.069	0.492
RT RI	0.106	0.295	0.104	0.303
RT S/D	0.124	0.219	0.119	0.237
LT IMT	0.015	0.885	0.103	0.307
LT PSV	0.037	0.714	− 0.061	0.549
LT EDV	0.018	0.862	− 0.067	0.505
LT RI	0.106	0.293	0.107	0.291
LT S/D	0.124	0.220	0.119	0.237

p value < 0.05 is significant, *r* coefficient of correlation

of the age group was 24–28 years (50.0%), which can be attributed to the younger age group of the Sudanese population.

Most smokers (33.0%) in the case group smoke 6–10 cigarettes a day, which may be due to study or work stress.

The study showed that the average IMT was higher in smokers than in non-smokers. This thickening slows blood flow in the common carotid artery and increases the risk of atherosclerotic changes in smokers. This finding is consistent with a study by Howard et al. [16], which found a strong association between active smoking and carotid IMT and provides initial evidence that passive smoking exposure is associated with increased IMT. Increasing exposure to cigarette smoke (either pack-years of active smoking or hours of passive smoking) was significantly associated with increased IMT [16].

Regarding the mean ± SD measurements of the Doppler parameters, the study showed a highly significant decrease in PSV in smokers compared to non-smokers, and EDV was decreased in smokers compared to non-smokers. This may be due to increased intima-media thickness associated with reduced diastolic blood flow velocity**.**

In addition, RI and S/D showed an insignificant difference between smokers and non-smokers. These results agree with a previous study by Azra Mahmud et al. [13], who found that the augmentation index (AIx) was significantly higher in smokers than in non-smokers at baseline. Although PWV was higher in smokers than in non-smokers, the difference was not statistically significant. No acute changes in hemodynamic parameters were observed after sham smoking.

With regard to gender in the study group, the study showed that the mean IMT in males was slightly lower than the mean in females. The Doppler parameters (PSV, RI, and S/D) were also statistically insignificantly different according to sex, except for EDV, which was found to be slightly lower in females than in males. These results were consistent with studies by Mahmoud et al., who found that the mean carotid IMT was slightly higher in females compared to males. He mentioned that the ranges of IMT found in the study were from 0.04 to 0.07 cm, and the mean carotid IMT was slightly higher in females compared to males. No significant differences were found between IMT and different ethnicities, but significance was found between the age of the participants and IMT in both sexes [17, 18]. This is also in agreement with the study by Younl et al., who examined the normative values and correlation of mean carotid intima-media thickness in healthy rural Korean adults and found that increasing IMT was correlated with Framingham risk scores in both sexes [19].

This study showed that the highest mean ± SD of IMT was found in the age group over 39 years, while the lowest mean ± SD of IMT was found in the age group 24–28 years. This finding was considered to be a significant positive correlation between the age of the study population and IMT, i.e., that IMT increases with increasing age, and was also consistent with previous studies that found that age influenced IMT in both sexes [17, 18].

According to the number of cigarettes smoked per day, the study showed that the lowest mean value of IMT was in the study population, which consumed 1–5 cigarettes per day, and the highest mean value of IMT was in the study population, which consumed 11–5 cigarettes per day. This suggests that IMT increased as the number of cigarettes smoked per day increased in chronic smokers.

Mahmoud studied the effect of the number of cigarettes smoked per day on the intima-media thickness (IMT) of the common carotid arteries in current Sudanese smokers. He showed that cigarette smoking is associated with morphological changes in the carotid arteries caused by a significant impairment in the endothelial function of the arteries. Greater structural and functional damage to the carotid artery was found to increase with the number of cigarettes smoked per day over a period of 5–10 years [18].

In our study, PSV increases and EDV decreases with the number of cigarettes consumed per day or by chronic smokers individually. This agrees with a study by Mahmoud et al. [20], who found that 26.7% smoked 1–4 cigarettes per day, 16% smoked 5–9 cigarettes per day, 53.3% smoked 10 or more cigarettes per day, and 4% were non-smokers. He found that increasing cigarette consumption per day in current smokers increased PSV and decreased EDV for the right and left common carotid arteries compared with values obtained from the never-smoker group. The results indicate that smoking status in current Sudanese smokers effectively influences PSV and EDV of the common carotid arteries in a positive and negative linear correlation, respectively [20].

Lee et al. conducted a study to investigate the variability of Doppler measurements along the extracranial courses of the healthy common carotid artery (CCA) and internal carotid artery (ICA) and to determine the effect of this variability on the assessment of carotid artery stenosis. The study found that there was significant variability in PSV and EDV between the right and left carotid arteries, which could be due to variability in Doppler ultrasound measurements along the common carotid artery [21].

4.1 Limitations of the Study

This study has several limitations. One of these limitations is the cross-sectional nature of the study design, so the participants were not followed up. In addition, the assessment of CCA-IMT was limited to measuring the distal segment of the common carotid arteries, and there was no data on the presence of carotid plaque, which is another important marker of atherosclerosis based on the consequences of increased stiffness. A longitudinal study is needed to better assess the relationships between cardiovascular risk factors, subclinical atherosclerosis, and the risk of cardiovascular events in the population. Another limitation of IMT is that it was measured manually due to the lack of automated technology in the region where the study was conducted; automated technology allows faster assessment with less variability for all carotid segments.

5 Conclusions

The mean IMT in smokers was greater than the mean in non-smokers, based on the mean ± SD of the ultrasound parameters. The study showed a decreased PSV and a highly significant decrease in EDV in smokers compared to non-smokers. RI and S/D showed insignificant differences between smokers and non-smokers. The study showed that there was a significant positive correlation between IMT, PSV, and EDV and the number of cigarettes smoked per day.

Regular follow-up with individuals with a history of smoking is recommended to detect carotid intimal changes earlier. Further research is needed to investigate the morphological changes caused by cigarette consumption in current and former smokers, in addition to the changes in blood flow velocity that occur in such cases.

Abbreviations

AIx	Augmentation index
B-mode	Brightness mode
CCA	Common carotid artery
CVD	Cardiovascular disease
ECA	External carotid artery
EDV	End diastolic velocity
ICA	Internal carotid artery
IMT	Intima-media thickness
PSV	Peak systolic velocity
PW	Pulsed wave
PWV	Pulse wave velocity
RI	Resistance index
S/D	Systolic–diastolic ratio
TDI	Tissue Doppler imaging

Acknowledgements
The authors would like to thank all participants who enthusiastically accepted to participate and devote their valuable time to the study.

Author Contributions
AMA contributed to data collection, analysis and wrote the initial and final manuscript. IAA comprehensively contributed to the study design and interpretation, and wrote and revised the final manuscript. All authors read and approved the final manuscript.

Funding
The study was self-funded by the authors.

Availability of Data and Materials
Data generated in this study are available from the corresponding author upon reasonable request with a completed Materials Transfer Agreement, excluding the materials including personally identifiable information.

Declarations

Conflict of Interest
The authors have no relevant financial or non-financial interest to disclose. The authors declare that they have no competing interests.

Ethics Approval and Consent to Participate
All procedures in studies involving human participants conformed to the ethical standards of the institutional and/or national research committee and to the 1964 Declaration of Helsinki and its subsequent amendments, or comparable ethical standards. Written informed consent was obtained from all participants. The study was approved by the scientific and ethical committee of the University of Medical Sciences and Technology (UMST). The objectives of the study were explained to all participants. Informed consent was obtained from each participant before the start of the study. The privacy and confidentiality of each patient included in this study were assured; no information about the patients was leaked, and all patients were treated equally. Participation was voluntary. The participant has the right to withdraw at any time without penalty. The participant has the right not to be harmed (privacy and confidentiality through the use of a coded questionnaire), and the privacy issues were deliberately considered. The participant has the right to benefit from the researcher's (authors') knowledge and skills. The result of the study was given to the patient and her doctor immediately, and the remaining blood sample will not be used for another study. Precautions for COVID-19 were taken.

Consent to Publication
Not applicable.

Author details
[1]Department of Ultrasonography, Ain Al Khaleej Hospital, Alain, Abu Dhabi, United Arab Emirates. [2]Department of Physiology, Faculty of Medicine, The National Ribat University, Khartoum, Sudan.

Received: 17 August 2023 Accepted: 5 January 2024
Published: 25 January 2024

References

1. Milenkovic U, Albersen M. Effect of Lifestyle on Men's Health. 2019. p. 303–19.
2. Doonan RJ, Hausvater A, Scallan C, Mikhailidis DP, Pilote L, Daskalopulou SS. The effect of smoking on arterial stiffness. Hypertens Res. 2010;33(5):398–410.
3. Allan P, Mowbray P, Lee A, Fowkes F. Relationship between carotid intima-media thickness and symptomatic and asymptomatic peripheral arterial disease: the Edinburgh artery study. Stroke J. 1997;28:348–53.
4. Djousse L, Myers R, Province M, Hunt S, Echfeldt J, Evans G, et al. Influence of apolipoprotein E, smoking, and alcohol intake on carotid atherosclerosis: National Heart, Lung, and Blood Institute Family Heart Stud. Stroke J. 2002;33:1357–61.
5. Calabia J, Torguet P, Garcia M, Garcia I, Martin N, Guasch B, Faur D, Valle's M. Doppler ultrasound in the measurement of pulse wave velocity. Cardiovasc Ultrasound. 2011;9:13.
6. Millasseau SC, Stewart AD, Patel SJ, Redwood SR, Chowienczyk PJ. Evaluation of carotid-femoral pulse wave velocity. Hypertension. 2005;45:222–6.
7. Rashid SA, Mahmud SA. Correlation between carotid artery intima-media thickness and luminal diameter with body mass index and other cardiovascular risk factors in adults. Sultan Qaboos Univ Med J. 2015;15(3):e344–50.
8. Simova I. Intima-media thickness: appropriate evaluation and proper measurement, described. e-J Cardiol Pract. 2015; 13(21).
9. Parish S, Arnold M, Clarke R, Du H, Wan E, Kurmi O, et al. Assessment of the role of carotid atherosclerosis in the association between major cardiovascular risk factors and ischemic stroke subtypes. JAMA Netw Open. 2019;2(5): e194873.
10. Van den Oord SC, Sijbrands EJ, ten Kate GL, van Klaveren D, van Domburg RT, van der Steen AF, et al. Carotid intima-media thickness for cardiovascular risk assessment: systematic review and meta-analysis. Atherosclerosis. 2013;228(1):1–11.
11. Lee CJ, Park S. The role of carotid ultrasound for cardiovascular risk stratification beyond traditional risk factors. Yonsei Med J. 2014;55(3):551–7.
12. Holaj R, Spacil J, Petrasek J, Malik J, Haas T, Aschermann M. Intima-media thickness of the common carotid artery is the significant predictor of angiographically proven coronary artery disease. Can Cardiol J. 2003;19:670–6.
13. Mahmud A, Feely J. Effect of smoking on arterial stiffness and pulse pressure amplification. Hypertension. 2003;41:183–7.
14. Lee W. General principle of carotid doppler ultrasonography. J Ultrasonogr. 2014;33(1):11–7.
15. Tahmasebpour HR, Buckley AR, Cooperberg PL, Fix CH. Sonographic examination of the carotid arteries. Radiographics. 2005;25(6):1561–75.
16. Howard G, Burke G, Szklo M, Tell G, Eckfeldt J, Evans G, et al. Active and passive smoking are associated with increased carotid wall thickness. The Atherosclerosis Risk in Communities Study. Arch Intern Med J. 2010;154:1277–82.
17. Mahmoud MZ. Sonography of common carotid arteries' intima-media thickness in the normal adult population. N Am J Med Sci. 2012;5:88–94.
18. Mahmoud MZ. Effect of cigarettes smoking on common carotid arteries intima-media thickness in current smokers. Ozean J Appl Sci. 2012;5(4):259–69.
19. Youn YJ, Lee NS, Kim JY, Lee JW, Sung JK, Ahn SG, et al. Normative values and correlates of mean common carotid intima-media thickness in the Korean rural middle-aged population: the Atherosclerosis Risk of Rural Areas in Korea General Population. J Korean Med Sci. 2011;26:365–71.
20. Mahmoud MZ. Smoking status effects on common carotid arteries peak systolic velocity and end diastolic velocity in current Sudanese smokers. Asian J Med Clin Sci. 2012;1(3):125–8.
21. Lee VS, Hertzberg BS, Kliewer MA, Carroll BA. Assessment of stenosis: implications of variability of Doppler measurements in normal-appearing carotid arteries. Radiol J. 1992;212(2):493–8.