International Journal of Medicine
pISSN 1468-3814 | eISSN 2667-7008
https://theinternationalmedicine.com/

Original Research Article *DOI: 10.61336/im/26-06-129*

ARTERIAL STIFFNESS ASSESSMENT AMONG SMOKERS &NON SMOKERS BY MEASURING STIFFNESS AND REFLECTION INDEX USING PHOTOPLETHYSMOGRAPHY (PPG)

[1]Dr.Uma. B.V, [2]Dr. K.N. Maruthy, [3]Dr. A. Sandeep, [4]Dr.G. Charita

[1]Professor, Physiology Department, Narayana Medical Collage, Nellore, Andhra Pradesh
[2]Professor, Physiology Department, PESIMSR, Kuppam, Andhra Pradesh
[3]MBBS, Narayana Medical Collage, Nellore, Andhra Pradesh
[4]MBBS, Narayana Medical Collage, Nellore, Andhra Pradesh

Correspondence:
Dr.Uma. B.V

Received: **May 10, 2026**
Revised: **May 25, 2026**
Accepted: **June 10, 2026**
Published: **June 23, 2026**

Abstract

Introduction: Cardiovascular disease (CVD) is the leading cause of mortality and morbidity worldwide. Smoking is one of the modifiable risk factor. Complications of arterial stiffening which results in cardiovascular disease because of the reduced elasticity in blood vessels. Chronic cigarette smoking has been shown to be associated with increased arterial stiffness due to changes in the vascular endothelium, induction of coronary vasoconstriction and changes in the basal nitric oxide (NO) or endothelial nitric oxide synthase production. Lifestyle modification is necessary to prevent complications .These complications of smoking are responsible for negative effect on quality of life. Hence it has become important that chronic complications are recognized early and necessary interventions are made. Measurement ofStiffness and Reflection index helps in assessment of arterial stiffness. ***Objectives:*** 1. To record finger pulse using Infra Red (IR) light Photo pulse plethesmography (PPG) device in smokers and non smokers 2. To measure stiffness (SI) and reflection index (RI) from the recorded pulse wave using Audacity software ***Methodology:*** After getting clearance from ethical committee, informed consent was taken from all the participants and different parameters were recorded as per study protocol. Data collection was done in the Department of Physiology, Narayana Medical College, Nellore. Finger pulse was recorded using photoplethysmography (PPG) module and the digital signal was recorded in audacity software. Finger pulse recording has two peaks-Systolic Blood Pressure and Diastolic Blood Pressure peaks. The length of this path corresponds to the subject's height (h). The time interval between the diastolic and systolic peak was taken as Pulse Transit Time. (PTT). Stiffness index & Reflection index were calculated using the formula to assess arterial stiffness. ***Results:*** In our study, we found that, Smokers had significantly higher stiffness index values than non smokers, $p > 0.001$, which indicates increased arterial stiffness. Reflection index values were significantly different in smokers compared to non smokers – this could be due to increased sympathetic drive in non smokers due to which the vascular tone might have increased. Many factorscan influence the vasculartone one such example is caffeine. Hence, the measurement of SI & RI may be more useful in the early identification of vascular changes, even in the absence of clinically apparent disease. ***Conclusion:*** Assessment of arterial stiffness in smokers by recording finger pulse which is a simple procedure and can be used as a screening tool for identification of persons who are at high risk. Increase in stiffness index indicates decreased arterial compliance. Increase in reflection index could be due to increased sympathetic drive which increases in vascular tone. As the arterial smooth muscle tone is altered by many factors eg - Stress and Caffeine. Since increased arterial stiffness is the hallmark of many cardiovascular disorders, early detection can reduce associated morbidity and mortality.

Keywords: Endothelial dysfunction, Pulse wave velocity ,Photoplethysmography, Arterial stiffness, Pulse Transit Time , Stiffness index

INTRODUCTION

Arterial stiffness is a growing epidemic associated with increased risk of cardiovascular events. Decreased compliance of the central vasculature alters arterial pressure and flow dynamics and impacts cardiac performance and coronary perfusion. Arterial stiffness indicates how hard the heart has to work to pump blood through the body.

Smoking is one of the primary cause of preventable illness. Smoking harms nearly every organ of the body and reduces both quality of life and life expectancy.

Most smoking-related deaths are due to lung cancer, chronic obstructive pulmonary disease (COPD) & Coronary Heart Diseases (CHD).

According to WHO estimation, tobacco continues to kill - 6 million people each year, more than 600,000 passive smokers (heart disease, lung cancer, and other illnesses). If current trends continue, the death toll may reach more than 8 million per year by 2030. Endothelial dysfunction is a broad term which implies impairment of the barrier functions of endothelial cells, vasodilation, disturbances in proliferative capacities, angiogenic properties, attenuation of synthetic function, and interruption in white blood cells from adhesion and diapedesis . Several factors contribute to endothelial dysfunction including smoking, high blood pressure, diabetes, high cholesterol levels, obesity, hyperglycemia, advance glycation end products (AGEs), and genetic factors. Stiffness affects the microvascular beds of various systems by increasing the left ventricular systolic load Smoking disturbs vascular endothelial homeostasis by reducing the bioavailability of vascular nitric oxide (NO), mainly via the formation of oxidative stress and inflammatory processes. Since the formation of NO plays a key role for the endothelium to interrupt its vasodilatory, antithrombotic, anti-inflammatory, and antioxidant functions. All these factors results in endothelial dysfunction and atherosclerotic plaque formation, ultimately leading to structural changes in the arterial wall and arterial stiffening. Basal NO production and other measures of endothelial dysfunction are very difficult to measure non-invasively. However, NO is a potent smooth muscle relaxant and is a principal regulator of arterial smooth muscle tone. In smokers, endothelial dysfunctions are responsible for negative effect on quality of life. Arterial stiffness is emerging as an interesting tissue biomarker for cardiovascular risk stratification. Hence it has become important that chronic complications are recognized early and necessary interventions are made. Arterial stiffness can be assessed by measuring stiffness index(SI) & Reflection index (RI). Arterial stiffness can be assessed using Pulse wave velocity (PWV) which is a graph, recorded using Photoplethysmography (PPG), non invasivetechnique , simple and cost-effective signal that indicates the pulsation of great arteries followed by the heartbeat and later digitised using Audacity software. A pulse wave refers to the pressure wave created during cardiac cycle, which travels along the arteries also propel the blood through them. It is an indicator of arterial wall stiffness and is used clinically in assessing arterial health. Pulse wave velocity (PWV) is an index of arterial stiffness. Here infrared light is transmitted through index finger to measure pulse wave. The plethysmogram waveform represents pulsatile peripheral blood flow, which reflects both peripheral and central hemodynamics. Photoplethysmography (APPG) helps us to know about vascular retro gradation by measuring stiffness index and reflexion index.

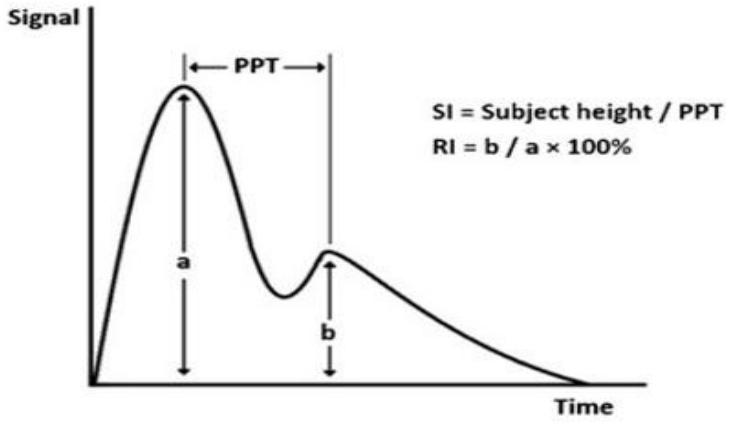
In the current study, the peripheral finger pulse was recorded using a PPG module and digitised using Audacity software. This PPG module records the Digital Volume Pulse (DVP), which has two peaks-Systolic Blood Pressure and Diastolic Blood Pressure peaks. The former peak is caused by pulse waves that are directly transmitted from the left ventricle to the finger. The diastolic peak results from pulse waves that are carried via the aorta to the small arteries in the lower body, where they are subsequently reflected back along the aorta as a reflected wave. The length of this path corresponds to the subject's height (h). The time interval between the diastolic and systolic peaks is known as the Pulse Transmit Time.(PTT)

The pulse waveform reflects the systolic and diastolic events during the cardiac cycle. Factors such as age, smoking & etc affect stiffness which in turn alters the waveform. Since increased arterial stiffness is the hallmark of many cardiovascular disorders, early detection can reduce associated morbidity and mortality. The arterial wall stiffness can be assessed by the measurement of the stiffness index (SI) and reflection index (RI). The principle behind using this technique is to determine the propagation of blood pressure and vascular diameter changes during the cardiac cycle to the peripheral vascular system. The primary aim of PPG is to observe the mechanical movement of the heart and the kinetics of blood flow.Since increased arterial stiffness is risk predictor of many cardiovascular disorders early detection can reduce associated morbidity and mortality.

The primary objective of our study is to record and compare SI & RI among smokers and non-smokers using the PPG module. Formula to calculate stiffness index (SI) &.Reflection index (RI)

Stiffness Index = Patients Height / Pulse Transit Time [Pulse Transit Time → Time delay between systolic peak & Diastolic peak]

Reflection Index =Magnitude of Diastolic peak / Magnitude of Systolic Peak X 100
Stiffness index& reflection index



OBJECTIVES

1. To record finger pulse using Infra Red (IR) light Photo pulse plethesmography (PPG) device in smokers and non smokers
2. To measure stiffness (SI) and reflection index (RI) from the recorded pulse wave in Audacity software

MATERIALS AND METHODS

Participants

- 30 Smokers - aged between 20 - 40yrs, with duration of smoking more than 1yrs.
- 30 Non smokers – aged between 20 – 40yrs

Inclusion criteria

- Patient aged 20 – 40 yrs
- Males
- Smokers using beedi/cigarette (more than 1yrs)
- No history of diabetes mellitus / Hypertension or other systemic disorders

Exclusion criteria

- Patient aged <20 and> 40 yrs
- History of diabetes mellitus / Hypertension or other systemic disorders
- Females
- Smokers (less than 1yrs)

Parameters

- Height -Stadiometer
- Weight - Digital weighing balance
- Body Mass Index (using formula weight in Kg/ height in meter square)
- Photo pulse plethysmography
- Stiffness index measures average Pulse Wave Velocity
- Reflection index measured by Magnitude of Diastolic peak / Magnitude of Systolic Peak X 100

Methodology

- Case control study
- After getting clearance from ethics committee, informed consent was taken from all the participants and different parameters were recorded as per study protocol.
- Data collection was done in the Department of Physiology, Narayana Medical College, Nellore.

The subject was asked to come to the laboratory between 9 to 11am, After instrumentation 10mts rest is given.

- Height, Weight were recorded
- Body mass index was calculated
- Finger pulse waves using finger pulse sensor connected to digital PPG (In house built)
- Stiffness index measured using PTT (pulse transit time) which was obtained using Audacity software

Reflection index measured by using b/a ratio as % in the recorded pulse wave using Image J software withthe help of screen shot captured and saved as jpeg image.

RESULTS

Table – 1: General characteristics of the subjects

Parameters	Non smokers Mean ± SD	Smokers Mean ± SD
Age (yrs)	18.6 ± 0.9	25.2 ± 8.5
Height (Cms)	174.9 ± 6.3	169.4 ± 7.1
Weight (Kgs)	69.4 ± 12.6	66.1 ± 15.5
BMI	22.7 ± 3.9	23.1 ± 5.7

Table – 2: Cardiovascular parameters of smokers

Parameters	Non smokers Mean ± SD	Smokers Mean ± SD	P value
Heart rate (resting)	76 ± 8.7	86 ± 9	< .001
SI	10.98 ± 2.39	14.12 ± 3.99	0.002
RI (%)	65.4 % ± 14.72	45.59% ±17.81	0.001

Note: All the three parameters are statistically significant as p value is less than 0.05

Finger 1: Pulse recording device

Finger 2: Digital finger pulse recording

In our study, we found that, Smokers had significantly higher stiffness index values than non smokers, p > 0.001, which indicates increased arterial stiffness.

But Reflection index values were not significant in smokers compared to non smokers, which indicates tone of arterial smooth muscles. Many factors affect tone of the arterial smooth muscles, nicotine is one among that

DISCUSSION

Cardiac sympathetic hyperactivity is a dominant feature in smokers.

Smoking is known to increase arterial stiffness. Endothelial damage is a central feature in the evolution of vascular disease induced by cigarette smoking and may act as a precursor for future atherosclerosis.

Inhalation of cigarette smoke results in activation adrenergic system. nicotine in tobacco stimulates the sympathetic system, release of adrenaline and nor adrenaline. The released catecholamine's bind to α1-adrenergic receptors on vascular smooth muscle to cause muscle contraction and thus a reduction in arterial dispensability and vasoconstriction .

Important endothelial vasodilators are nitric oxide (NO) and prostacyclin. Nitric oxide is a dominant local regulator of resting vasomotor tone. In non smokers, vasoconstrictor response is soon counterbalanced by the local release of vasodilators from endothelium.
According to previous studies, smoking causes many adverse effects like disturbs NO production, affects cholesterol metabolism, by lowering levels of high-density lipoprotein (HDL) cholesterol, also can affect the blood clotting system, including adherence of blood platelets to the lining of arterial blood vessels, and the formation of blood clots that block a narrowed artery.

Measuring stiffness index & reflection index provides information regarding the arterial stiffness.Early identification of vascular changes can reduce the mortality & morbidity rate.

Smoking cessation is an important lifestyle measure for the prevention of cardiovascular disease. Quitting smoking has immediate and long term health effects such as improved circulation.

CONCLUSION

- So assessment of arterial stiffness in smokers by recording finger pulse which is a simple screening tool for identification of person who is at high risk and it indicates prompt cessation of the smoking habit, especially in young people.
- Smoking cessation programs like COTPA Act 2003

1) Prohibition of public smoking
2) Prohibition of advertisement of tobacco products
3) Restriction of sales to minors
4) Warning symbol on the cigar pack cover
5) GST should be increased strictly.

- Further research work in this field may help in preventing complications of smoking due to endothelial dysfunction.

REFERENCES

1, Omar Hahad et al "Chronic cigarette smoking is associated with increased arterial stiffness in men and women: evidence from a large population-based cohort" 2023; 112(2): 270–284, Clinical Research in Cardiology.

2, Fuster V, Wayne AR, O'Rouke RA (2001). Hurst's The Heart (10th International ed.). New York: McGraw-Hill. ISBN 978-0-07-116296-8. OCLC 49034333.

3, Saab PG, Llabre MM, Hurwitz BE, Schneiderman N, Wohlgemuth W, et al. The cold pressor test: vascular and myocardial response patterns and their stability. Psychophysiology. 1993;30:366–373. [PubMed] [Google Scholar] [Ref list]

4. Andreas J. Flammer, et al, " The Assessment of Endothelial Function From Research Into Clinical Practice Circulation" 2012 ;126 :753 -767, 2012 American Heart Association, Inc.

5. Andres Schanzer et al " Use of digital pressure measurements for the diagnosis of AV access-induced hand ischemia" Vascular Medicine 2006 ; 11: 227–231.

6. Amandeep Kaur etal, " Effect of Cigarette Smoking on Heart Rate Variability in Healthy Adult Smokers in The Age of 20-60 Years " IOSR Journal of Dental and Medical Sciences Department Of Physiology, Government Medical College, Patiala, Punjab, India., Vol-16, Issue 3 March. 2017, 69-73 , ISSN: 2279- 0853.

7. Mahesh Kumar J Patil etal, "Influence of cigarette smoking on human cardiovascular sympathetic autonomic functions", National Journal of Physiology, Pharmacy and Pharmacology, Department of Physiology, SVS Medical College, Telangana, february 10, 2017, Vol7 , Issue 6.

8. GeorGe Pa Pathanasiou etal, " Effects of Smoking on Heart Rate at Rest and During Exercise, and on Heart Rate Recovery, in Young Adults " Hellenic Journal of Cardiology , Department of Internal Medicine, Division of Cardiology, Medical School, University of Ioannina, September 17, Hellenic J Cardiol 2013; 54: 168-177

9, Giuseppina Gallucci1 etal, Cardiovascular risk of smoking and benefits of smoking cessation ,Journal of Thoracic Disease, Review Article on Improving Outcomes in Lung Cancer Through Early Diagnosis and Smoking Cessation , Vol 12, No 7 July 2020

10, Tian Xu, MD*; Xiaoqing Bu, MD*; Hongmei Li et al, Smoking, Heart Rate, and Ischemic Stroke, "A Population-Based Prospective Cohort Study Among Inner Mongolians in China" Stroke is available at http://stroke.ahajournals.orgownloaded from http://ahajournals.org by on September 30, 2024

11,ReviewArticle ,Endothelial Dysfunction and Diabetes: Effects on Angiogenesis, Vascular Remodeling, and Wound Healing, Gopi Krishna Kolluru, Shyamal C. Bir, and Christopher G. Kevil)