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ORIGINAL ARTICLE

Ankle Hemodynamic Index to Assess the Severity of Peripheral Arterial Disease Compared to Ankle Brachial Index

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ABSTRACT

Aims: The goal of this study is to assess the diagnostic efficacy of the “ankle-brachial index, ankle hemodynamic index (Tanno et al, 2016) correlated with the Rutherford grading of lower limb ischemia” in patients with angiographically proven peripheral artery disease as assessed by either CT or contrast angiography of the lower extremities as imaging modalities.
Methods: This observational cross-sectional study included 100 participants with proven peripheral artery disease who were referred to Nasr city health insurance hospital's vascular department and outpatient clinic.
Results: Study participants ranged in age from 35-86. The mean age of the participants was 63.6 ± 10.5 years. They were 70 males (70%) and 30 females (30%). The ankle-brachial index value ranged from 0.6 up to 1.3 for all of the participants that were evaluated, with a mean of 1 and a standard deviation of 0.2. Ankle hemodynamic index ranged from 17 to 73, with 17 being the lowest possible value and 73 being the highest possible value. The mean ankle hemodynamic index was 41.2 ± 13.4.
Ankle hemodynamic index and Rutherford grade have an extremely statistically significant positive correlation.
Conclusion: In conclusion, the AHI was shown to be substantially positively connected with the severity of PAD as assessed by Rutherford grading, but the ABI was found to be non-significantly associated with Rutherford grading. We also discovered that Rutherford grade was linked to HbA1C, Hb, CRP, and ankle DBP.
Keywords: Peripheral artery disease, ankle hemodynamic index, Rutherford grading, ankle-brachial index.

INTRODUCTION

Peripheral artery disease is a symptom of systemic atherosclerosis; hence, it follows the same pattern of progressive development. Peripheral artery disease is a sign of diffuse atherosclerosis in other vascular trees. In addition, there is a substantial overlap between peripheral artery disease, coronary artery disease, and cerebrovascular disease with peripheral artery disease being associated with an elevated risk of cerebrovascular disease and coronary artery disease and their consequences (Kennedy, 2005). (1)

Arterial illnesses other than coronary arteries and the aorta are referred to as 'peripheral arterial diseases'. This should be contrasted with the phrase 'peripheral artery disease,' which is frequently used to refer to arterial disease in the lower extremities (LEAD) (Tendera et al, 2017). (2)

Peripheral arterial disease affects blacks disproportionately, according to an earlier epidemiologic study, with a two to three-fold higher prevalence than whites. Asians, on the other hand, have a somewhat lower incidence of PAD than whites (Faxon et al, 2004). (3)

The ankle-brachial index is a non-invasive and inexpensive test and is widely used clinically to confirm a diagnosis of lower limb peripheral arterial disease (Crawford F et al, 2016). (4)

However, patients with profoundly stenotic iliofemoral arteries, on the other hand, may have a normal resting ankle-brachial index regardless of the severity of their ischemic symptoms.

Ankle hemodynamic index (AHI), a unique index derived from ABI values, may be used to non-invasively and objectively detect insufficient blood flow in affected limbs and could be correlated with ischemic symptoms (Tanno et al, 2016). (5)

Tanno et al. (2016) stated, “The ratio of arterial stiffness to vascular resistance at the ankle is what's described as the ankle hemodynamic index.”

$$\text{Ankle hemodynamic index} = \frac{\text{Stiffness}}{\text{Resistance}}$$

In patients with peripheral artery disease, atherosclerosis makes arteries stiffer (Tanno et al, 2016) and lowers vascular resistance, reducing blood flow and causing symptoms.

As a measure of the ankle vasculature's resistance to blood flow, ankle vascular resistance (Hirsch et al, 2006) (6) can be calculated as the pressure difference (mean arterial pressure) at the ankle divided by blood flow.

The change in volume of blood (V) pumped each heartbeat divided by its pressure (P) is what's known as an ankle's vascular compliance, which may be represented as (stroke volume/ankle pulse pressure) since it measures how much blood flows through the ankle in one heartbeat (Chirinos JA, 2010; London GM, 1999). (7,8)

As a result, “ankle arterial stiffness may be represented as ankle pulse pressure/stroke volume, which is the reverse of vascular compliance.” (Tanno et al, 2016).

Tanno et al. (2016) hypothesized that “lower ankle resistance and higher ankle stiffness may play a key part in the affected limb's insufficient blood supply.”

$$\text{AHI} = \frac{\text{ankle pulse pressure (PP)} \times \text{heart rate}}{\text{(MAP) at the ankle}}$$

SUBJECTS AND METHODS

This observational cross-sectional study included 100 participants with peripheral arterial disease who were referred to Nasr city health insurance hospital's vascular department and outpatient clinic.

Inclusion criteria: Patients with symptomatic peripheral artery disease (claudication, rest pain, or critical limb ischemia) who have severe stenotic lesions of the lower extremities on contrast or CT angiography (>50 percent diameter stenosis on visual estimate).

Exclusion Criteria: Acute limb ischemia, patients with prior lower extremity revascularization, patients with conditions that would interfere with the measurement of the ankle parameters (amputation/surgery, lower limb trauma, leg ulcers, deep vein thrombosis), and patients with concomitant serious illness (malignancy, end-stage renal dysfunction, and end-stage liver failure. etc.).

Methods:

Each patient was subjected to the following:

Full medical history: Age, gender, smoking, hypertension, diabetes, dyslipidemia, obesity, personal or family history of coronary artery disease, stroke, or vascular disease, and symptoms of lower extremity artery disease such as atypical lower limb pain, intermittent claudication, pain at rest, non-healing sores, or gangrene.

Physical examination: Cold dry skin, erythematous discoloration of the limb in a dependent position, loss of hair, hypertrophic toenails, non-healing wounds, ulcers, or gangrene, and weak pulses are some of the physical examination outcomes.
Studied parameters: After resting for 5 minutes in the supine posture, all patients were assessed for ankle systolic and diastolic blood pressure, brachial systolic blood pressure, mean ankle arterial blood pressure, ankle pulse pressure, and heart rate to calculate ankle hemodynamic index and ankle-brachial index. Measurements were taken using an automated oscillometric blood pressure device and doppler ultrasound
Rutherford classification: "Stage 0 is asymptomatic, stage 1 is mild claudication, stage 2 is moderate claudication, stage 3 is severe claudication, stage 4 is rest discomfort, (Rutherford, 1997) and stage 5 is ischemic ulceration of the digits (minor tissue loss) of the foot, and stage 6 frank gangrene (major tissue loss) or severe ischemic ulcers." (9)
Laboratory investigations: Random blood sugar, glycosylated hemoglobin (HBA1C), serum creatinine, hemoglobin, and C-reactive protein (CRP)
Imaging modalities: All patients had a contrast or CT angiography to find out whether there was any severe stenosis (>50% diameter stenosis) and to determine the site of occlusion (iliofemoral, superficial femoral artery, popliteal artery, etc.)
Statistical analysis: "The data were analyzed using the Statistical Program for Social Science (SPSS) version 24. To express quantitative data, the mean SD (for normally distributed data) and median (IQR) was utilized (for abnormally distributed data)." Frequencies and percentages were used to convey qualitative data. The variables were tested using the independent-samples t-test of relevance (for normally distributed data). The Mann–Whitney U test was used to compare two means (for abnormally distributed data). "When examining more than two variables, a one-way analysis of variance (ANOVA) is used (for normally distributed data). When comparing more than two means, the Kruskal Willis test (KW) is used (for abnormally distributed data)."

RESULTS

Study participants ranged in age from 35-86. "The mean age of the participants was 63.6 ± 10.5 years. They were 70 males (70%) and 30 females (30%). As regards risk factors, they were 80 diabetic patients (80%), 66 hypertensive patients (66%), 58 smoker patients (58%), 46 dyslipidemic patients (46%), 31 obese patients (31%), 32 patients (32%) with a positive personal history of CVD and 5 patients (32%) with a positive family history of CVD in the patients analyzed. " Table (1)

Table 1: Description of demographic profile for all patients evaluated

		Number of patients (N = 100)	
Age (years)	Median ±SD	63.6 ± 10.5	
	Min - Max	35 – 86	
Sex	Male	70	70%
	Female	30	30%
Diabetes mellitus	No	20	20%
	Yes	80	80%
Hypertension	No	34	34%
	Yes	66	66%
Smoking	No	42	42%
	Yes	58	58%
Dyslipidemia	No	54	54%
	Yes	46	46%
Obesity	No	69	69%
	Yes	31	31%
Personal history CVD	No	68	68%
	Yes	32	32%
Family history CVD	No	95	95%
	Yes	5	5%

Regarding Rutherford stage in all studied patients. It was stage 1 in 9 patients (9%), Stage 2 in 16 patients (16%), Stage 3 in 13 patients (13%), Stage 4 in 19 patients (19%), Stage 5 in 26 patients (26%) and Stage 6 in 17 patients (17%). Table (2)

Table 2: Description of Rutherford stage.

	Studied patients (N = 100)		
Rutherford stage	Stage I	9	9%
	Stage II	16	16%
	Stage III	13	13%
	Stage IV	19	19%
	Stage V	26	26%
	Stage VI	17	17%

"Regarding the studied parameters, the mean ankle systolic blood pressure (SBP) was 124.4 ± 17.7 mmHg with a minimum ankle SBP of 80 mmHg and maximum ankle SBP of 160 mmHg." The mean ankle diastolic blood pressure (DBP) of all studied patients was 79.2 ± 15 mmHg with a minimum ankle DBP of 60 mmHg and maximum ankle DBP of 120 mmHg. The mean brachial SBP of all patients analyzed was 128.9 ± 21.9 mmHg with minimum brachial SBP of 90 mmHg and maximum brachial SBP of 190 mmHg. The mean ankle pulse pressure (PP) of all studied patients was 45.2 ± 11.4 with a minimum ankle pulse of 20 and a maximum ankle pulse of 70. The mean ankle arterial pressure (MAP) of all patients analyzed was 93.9 ± 15.8 mmHg with a minimum ankle MAP of 43 mmHg and maximum ankle MAP of 130 mmHg. As regards heart rate (HR), the mean HR of all studied patients was 84 ± 11 beats/min with a minimum HR of 60 beats/min and maximum HR of 110 beats/min. "As regards ABI, the mean ankle-brachial index was 1 ± 0.2 with a minimum ABI of 0.6 and a maximum ABI of 1.3. As regards AHI, the mean ankle hemodynamic index was 41.2 ± 13.4 with minimum AHI of 17 and maximum AHI of 73." Table (3)

Table 3: Description of studied parameters.

(n = 100)	Minimum	Maximum	Mean	±SD
Ankle SBP	80	160	124.4	17.7
Ankle DBP	60	120	79.2	15.0
Brachial SBP	90	190	128.9	21.9
Ankle Pulse pressure	20	70	45.2	11.4
Ankle MAP	43	130	93.9	15.8
HR	60	110	84.0	11.0
ABI	0.6	1.3	1.0	0.2
AHI	17	73	41.2	13.4

The correlation between the Rutherford stage and other investigated data Table (4) reveals a "significant statistical positive correlation (r = 0.28) between random blood sugar (RBS) and Rutherford stage" Figure (1). The correlation between C-reactive protein and Rutherford stage was positive (r = 0.56) and highly statistically significant Figure (2). In all studied patients and diabetic patients, ankle hemodynamic index and Rutherford stage were "positively correlated (r = 0.8 and 0.78 respectively) with a highly statistically significant value (p-value < 0.001)."

Table 4: Correlation between Rutherford grade and other studied data in all patients and in diabetic patients.

Variables	All patients		DM patients	
	r	p-value	r	p-value
Rutherford grade vs RBS	0.28	0.005 S	0.14	0.202 NS
Rutherford grade vs HbA1C	0.60	< 0.001 HS	0.61	< 0.001 HS
Rutherford grade vs Creat	0.12	0.242 NS	0.01	0.916 NS
Rutherford grade vs Hb	-0.28	0.005 S	-0.25	0.029 S
Rutherford grade vs CRP	0.56	< 0.001 HS	0.51	< 0.001 HS
Rutherford grade vs EF	-0.24	0.019 S	-0.15	0.183 NS
Rutherford grade vs Ankle SBP	0.04	0.717 NS	0.12	0.29 NS
Rutherford grade vs Ankle DBP	-0.47	< 0.001 HS	-0.39	< 0.001 HS
Rutherford grade vs Brachial SBP	0.14	0.167 NS	0.22	0.045 S

Rutherford grade vs Ankle PP	0.68	< 0.001 HS	0.67	< 0.001 HS
Rutherford grade vs Ankle MAP	-0.27	0.006 S	-0.16	0.147 NS
Rutherford grade vs HR	0.39	< 0.001 HS	0.40	< 0.001 HS
Rutherford grade vs ABI	-0.11	0.264 NS	-0.15	0.199 NS
Rutherford grade vs AHI	0.80	< 0.001 HS	0.78	< 0.001 HS

" (r): correlation coefficient. S (significant): p-value < 0.05, HS (highly significant): p-value < 0.001. NS(non-significant): p-value > 0.05."

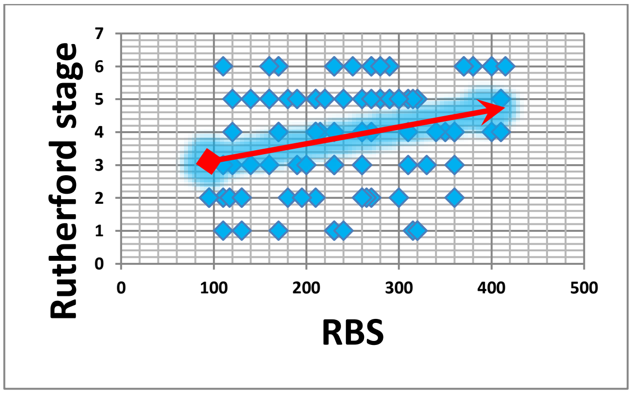

Figure 1: Positive correlation between Rutherford stage and RBS in all patients.

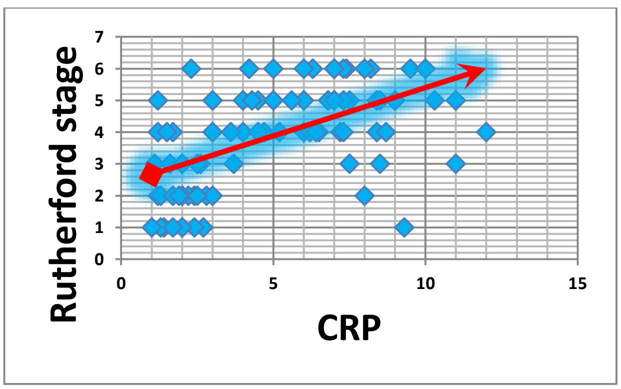

Figure 2: Positive correlation between Rutherford stage and CRP in all patients

DISCUSSION

The symptom-based Rutherford and Fontaine classifications (Fontaine R et al, 1954) (10) are the most often used schemes to determine the degree of ischemia in patients with peripheral artery diseases (6). The revascularization potential of ischemia in the lower limbs can also be assessed using the Rutherford classification system (Rutherford, 1997) (9).

This study was principally designed to evaluate the diagnostic efficacy of the ankle-brachial index and the ankle hemodynamic index (Tanno et al, 2016) correlated with the Rutherford classification of lower limb ischemia in patients with angiographically proven peripheral artery disease as assessed by either CT or contrast angiography of the lower extremities as imaging modalities.

The current study was supported by a pilot study by Tanno et al. (2016), which aimed to "identify independent factors related to the Rutherford classification system by using the ankle hemodynamic index, as well as to assess the correlation between the ankle-brachial index, the ankle hemodynamic index, and Rutherford grade. Significant lesions were found on lower limb angiography of patients with an average age of 72 (65.0–76.0) years (60 males and 25 females). The patients were predominantly elderly males who were not overweight and had a normal left ventricular systolic function. Hyperglycemia was found in 54 (63.5%) of the 85 patients, as well as high blood pressure in 65 (76.5%) and dyslipidemia in 40 (47.1%). Hemodialysis patients and patients with collagen conditions were found in 22 (25.9%) and 10 (11.8%) of the cases, respectively." (5)

Regarding Rutherford stage (Rutherford, 1997) among the studied patients, the current study showed that It was stage 1 in 9 patients (9%), Stage 2 in 16 patients (16%), Stage 3 in 13 patients (13%), Stage 4 in 19 patients (19%), Stage 5 in 26 patients (26%) and Stage 6 in 17 patients (17%) in the studied patients.

In line with our results, Tanno et al. (2016) reported that "the median Rutherford grade was 3; 8 patients (9.4%) had Rutherford grade 1, 13 patients (15.3%) grade 2, 23 patients (27.1%) grade 3, 4 patients (4.7%) grade 4, 15 patients (17.6%) grade 5, and 22 patients (25.9%) grade 6."

The ankle-brachial index value ranged from 0.6 up to 1.3 for all of the participants that were evaluated, with a mean of 1 and a standard deviation of 0.2. Ankle hemodynamic index ranged from 17 to 73, with 17 being the lowest possible value and 73 being the highest possible value. The mean ankle hemodynamic index was 41.2 ± 13.4.

The study by Tanno et al. (2016) reported that "the mean ABI was 0.69 ± 0.16, and the mean AHI was 30.4 (21.0–46.9)."

Correlation between "Rutherford stage and other parameters in all patients in our study showed that there was a significant statistical positive correlation (r = 0.28) between random blood sugar, glycosylated hemoglobin, C-reactive protein, ankle pulse pressure, heart rate, ankle hemodynamic index and Rutherford grade and significant statistical negative correlation between hemoglobin level, ankle diastolic pressure, ankle mean arterial pressure and Rutherford stage. As regards ankle-brachial index, there was a non-statistically significant correlation with Rutherford grade."

In line with our findings, Tanno et al. (2016) found a "strong correlation between ankle hemodynamic index and Rutherford grade but not between ankle-brachial index and Rutherford grade."

As well, the study by (Abigail L et al, 2019) (11) reported that "there were no relationships between the ankle-brachial index and the quality of life and symptoms scores on the Peripheral Artery Questionnaire (PAQ). The Rutherford classification exhibited a greater, although still minor, relationship with the PAQ scores."

In agreement with our study, (Chuter VH et Al, 2021) (12) "performed a systematic review and meta-analysis of the ankle-brachial index (ABI)for detecting peripheral arterial disease in diabetics, finding that the ABI has a low sensitivity but high specificity in detecting imaging-diagnosed PAD in people with diabetes. The ABI's poor efficacy for early identification of PAD is suggested by the low probability of the tests being able to rule diagnosis in or out."

Desormais I et al. 2014 stated, "RBCs and circulating hemoglobin are involved in both pathologic and physiological processes, such as blood viscosity abnormalities, oxidative stress, and inflammatory processes." (13) Anemia will worsen their lower limb ischemia since RBCs and hemoglobin both play a role in controlling functional capacity in people with peripheral artery disease (Coutinho T et al, 2011) (14).

Khawaja FJ et al, 2007 "investigated the association of risk factors including C-reactive protein (CRP) and other inflammatory markers such as fibrinogen and homocysteine with the ankle-brachial index and stated that those risk factors are associated with interindividual variation in ABI in African American and non-Hispanic white populations and partly account for the increased risk of PAD." (15)

In our research, anemia was only weakly correlated to the Rutherford grade and C-reactive protein showed a significant statistical positive correlation with the Rutherford grade. As a consequence, anemia and C-reactive protein levels might be used as indirect indicators of lower limb ischemia caused by PAD.

By reflecting hemodynamic components such as ankle systolic blood pressure, diastolic blood pressure, and heart rate, the ankle hemodynamic index (Tanno et al., 2016) may be able to predict the severity of lower limb ischemia as determined by the Rutherford classification.

In this study, ankle hemodynamic index was found to be an independent predictor of the Rutherford grade. Unlike anemia and CRP levels, the ankle hemodynamic index gives a direct measure of blood flow insufficiency in PAD patients.

CONCLUSION

In conclusion, the current investigation reported that The AHI was strongly linked with the severity of PAD as determined by Rutherford grading; however, the ABI was not associated with Rutherford grading. Additionally, we discovered a strong correlation between Rutherford grade and HbA1C, Hb, CRP, and ankle DBP. In addition to the ankle pulse pressure and HR, it was linked with Brachial SBP in the DM group and with RBS, EF, and ankle MAP in all cohorts analyzed. In comparison to other diagnostic procedures, AHI is advantageous since it is a straightforward, non-invasive test that can be performed on all patients regularly.

Declarations: Consent for Publication: I certify that all authors have agreed to submit the paper for publication.

Availability of data and material: Available

Competing interests: none

Conflicts of Interest: no conflicts of interest in connection with the publication of this article.

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