Role of ankle peak systolic velocity as a hemodynamic predictor following infrainguinal arterial angioplasty

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Background

Infrainguinal arterial disease is a common vascular problem. It is associated with decreased quality of life and possible major limb loss. Critical limb ischemia (CLI) generally occurs in diabetics with extensive atherosclerotic disease of below-knee vessels. The optimal strategy for treating patients with CLI, however, has not been clearly defined yet. The outcome of medical therapy is unsatisfactory, and early aggressive percutaneous revascularization with the aim of obtaining direct flow to the foot is increasingly considered a first-line strategy. This study was carried out to evaluate ankle peak systolic velocity (APSV) as a hemodynamic predictor following endovascular intervention of those patients.

Objective

The aim of the study was to validate APSV as a predictor of success and a potential alternative to Ankle Brachial Index (ABI) as an objective performance measure following infrainguinal angioplasty.

Patients and methods

A total of 45 patients with CLI Rutherford stage 4–6 were enrolled in the study. This was a prospective nonrandomized cohort study conducted in El-Sahel Teaching Hospital and Ain Shams Hospitals. All patients underwent full history taking, foot examination, and measurements of APSV and ABI. A total of 45 patients were included from the Vascular Surgery Department of Ain Shams University Hospitals, El Sahel Teaching Hospitals (and other authorized hospitals under supervision of thesis supervisors). All of them were subjected to the following: an assessment of full history; physical examination, including foot examination; Doppler examination; measurement of APSV, and ABI; and routine investigations. This was a prospective nonrandomized cohort study (interventional analytical clinical study).

Results

APSV shows significant increase of ∼86.50% after intervention than before intervention. It shows also a significant increase in follow-up at 6-month period following intervention. There was a significant difference of the APSV before and after revascularization (18.70±8.04 vs. 31.50±12.60 cm/s) $P<0.001$. Regarding mean ABI, there was no statistically significant difference when comparing postoperative and 6-month follow-up results with preoperative results. Of 29 patients, 23 patients reached the end point of adequate healing or complete healing. Patients with healed ulcer show mean±SD APSV (36.52±8.14**)** that is equal to ABI (0.93±0.17).

Conclusion

APSV could predict the healing of lesions in patients with CLI, with a high degree of accuracy. It can be used as an alternative parameter to ABI in following up the patients after infrainguinal arterial angioplasty, especially in the presence of arterial calcification.

Keywords:
ankle brachial index, ankle peak systolic velocity, critical limb ischemia, peripheral vascular disease

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Introduction

Duplex scan is widely used for the assessment of arterial tree of the lower extremities in patients with peripheral arterial disease. It is used for assessment before angioplasty and operative intervention [1]. It is well established and has proved to be an effective and accurate modality for preoperative planning and arterial mapping. It has been shown to have comparable accuracy at lower cost compared with computed tomography angiography. Following the procedure, Ankle Brachial Index (ABI) improvement and patency of reconstruction are similar when duplex ultrasound or computed tomography angiography is used for preoperative planning [2].

ABI, the most common physiologic parameter used to assess peripheral arterial disease (PAD) severity, lacks anatomic precision but inaccurately assesses lower extremity perfusion in patients with highly calcified, noncompressible tibial arteries [3].

A new alternative parameter for the assessment of degree of peripheral ischemia is ankle peak systolic velocity (APSV). APSV strongly correlates with ABI and with toe brachial index (TBI) whenever those can be reliably measured. APSV is not affected by vessel calcification and can be measured in the presence of toe gangrene or amputation; therefore, APSV is advantageous in those situations. Moreover, it can be measured during arterial duplex scanning of the lower extremities [4].

Nevertheless, with the occurrence of arterial wall calcification, ABI is not accurate, as its results of being false are high. There is an alternative to this approach: the TBI [5]. However, diabetic patients have remarkable higher incidence of calcification of digital artery. Moreover, in some situation, as the toes are affected by ulcers or gangrene or have been amputated, we cannot measure toe pressures in those patients presenting with diabetic foot lesions. Therefore, TBI is invalid for assessment [6].

This study compares angiographic success, clinical success, ABI, and APSV to assess if APSV can be a hemodynamic predictor of success and an alternative to ABI as an objective performance measure after infrainguinal angioplasty for infrainguinal arterial disease.

Aim

The aim of this study was to compare angiographic success, clinical success, ABI, and APSV to assess if APSV can be a predictor of success and an alternative to ABI as an objective performance measure after infrainguinal arterial angioplasty for infrainguinal arterial disease.

Patients and methods

This is a prospective nonrandomized cohort study (interventional analytical clinical Study) that included patients with critical limb ischemia (CLI) being treated for infrainguinal arterial disease with angioplasty who presented to the vascular surgery clinics at Ain Shams University (El Demerdash) and El Sahel Teaching Hospital.

The study plan was accepted by the Ethical Committee of Ain Shams University Hospital.

The study included 45 consecutive limbs, with the following inclusion and exclusion criteria:

Inclusion criteria:

(1) Adult patient with history of CLI as defined by Rutherford class 4–6 [7].
(2) Any arterial lesion below the level of the common femoral artery (CFA) (intact CFA pulsation).
(3) Adequate distal runoff [intact pedal arch examined by 8-MHZ Doppler probe placed in the first metatarsal space; presence of Doppler signal is taken as a patent pedal arch, and also arterial flow in the form of biphasic or triphasic signals through either lateral branch of plantar pedal artery or dorsal pedal artery or flow in dorsalis pedis artery (DPA)].

Exclusion criteria:

(1) Severe foot infection that renders the limb unsalvageable.
(2) Patients have previous endovascular or open revascularization.
(3) Failure during endovascular intervention (acute thrombosis, failure to cross the lesion, or perforation).
(4) Presence of aortic, iliac, femoral, or popliteal aneurysm.
(5) Patient refusal to participate or absence of written consent.
(6) Patients known to have allergy to contrast, heparin, aspirin, or other antithrombotic agents.

Methods

Patient evaluation

All patients were subjected to the following: full history taking, including age, sex, history of hypertension, smoking, obesity, diabetes mellitus (DM), hypercholesterolemia, ischemic heart disease, congestive heart failure, cerebrovascular accident hepatic or renal insufficiency, preintervention medications, and symptoms of CLI (claudication, rest pain, and previous amputations), and clinical examination, including ulcer, characteristics of ulcer, gangrene, and pulsations). Presenting symptoms and signs were classified according to Rutherford classification and Fontaine classification. Laboratory investigation required for the procedure was done. ABI before the procedure and after the procedure was done. Duplex-detected APSV measurement of the affected limb before the procedure and after the procedure was done. All patients who were included according to inclusion and exclusion criteria were asked to sign informed consent explaining the nature of the intended procedure, benefits, and all its possible complications. Only patients who were able to sign the consent, agreed to be part of the study, and agreed for postprocedural follow-up visits were included in the study. Each patient according to its lesion underwent angioplasty with or without stenting, and details were taken about anesthesia type, access, sheaths, guidewire, catheters, balloon size, type, stent size and type, drug-eluting balloon, and duration of the procedure.

Duplex scanning was performed by an experienced operator. Duplex scan was performed using an ATL HDI 3000 machine (Phillips/Advanced Technology Laboratories, Bothell, Washington and Phillips Medical Systems, Eindhoven, The Netherlands). APSV is the mean of the peak systolic velocities of the anterior and posterior tibial arteries (PTAs) measured at the ankle level. A 5-MHz convex probe was used for the aorta and iliac arteries, and a 5- to 12-MHz linear transducer was used for infrainguinal arteries. The Doppler angle of insonation was adjusted to 60 μ. All patients were rested 1 h before scanning and were examined in supine position. Recordings were made with the room temperature adjusted to 22°C. Peak systolic velocities of the distal PTA at or below the malleolar level and the distal anterior tibial artery (ATA) just above the ankle joint level were recorded. Peak systolic velocities were averaged over three cardiac cycles. If focal stenotic lesion was detected in one of the distal tibial arteries, velocity measurements were taken distal to the stenosis. No alterations were made to the patient's medications before scanning.

All patients' ABI and APSV were taken immediately after intervention and after 6 months. Postoperative medications included antiplatelet, anticoagulation, vasodilators, and statins. Minor amputations needed after interventions were done. Primary end point was comparison between APSV and ABI before and after intervention and their relation to clinical improvement.

Primary outcome is clinical improvement as assessed by Rutherford classification, ABI, and APSV, whereas secondary outcome was major adverse limb event.

Statistical analysis

Recorded data were analyzed using the statistical package for social sciences, version 20.0 (SPSS Inc., Chicago, Illinois, USA). Quantitative data were expressed as mean±SD. Qualitative data were expressed as frequency and percentage. Significance of the probability (*P* value) was set as follows: **P* value less than or equal to 0.05 was considered significant, ***P* value less than or equal to 0.001 was considered as highly significant, and *P* value greater than 0.05 was considered insignificant.

Results

The study included 45 limbs, belonging to 45 patients. Their mean age was 62.58±9.58 years (Table 1).

The demographic characteristics and risk factor distribution are shown in Tables 1 and 2.

There were 38 (84.4%) patients who presented with rest pain. The table also showed that 31 (68.9%) patients presented with ulcer, whereas 30 (66.7%) patients with gangrene. Furthermore, 21 (46.7%) patients had popliteal pulse on examination. Results also showed that 10 (22.2%) patients presented with severe claudication (Table 3).

There were three (6.7%) patients with Rutherford Classification 3, five (11.1%) patients with Rutherford Classification 4, and 37 (82.2%) patients with Rutherford Classification 5. In addition, there were two (4.4%) patients with Fontaine Classification 2b, six (13.3%) patients with Fontaine Classification 3, and 37 (82.2%) patients with Fontaine Classification 4 (Table 4).

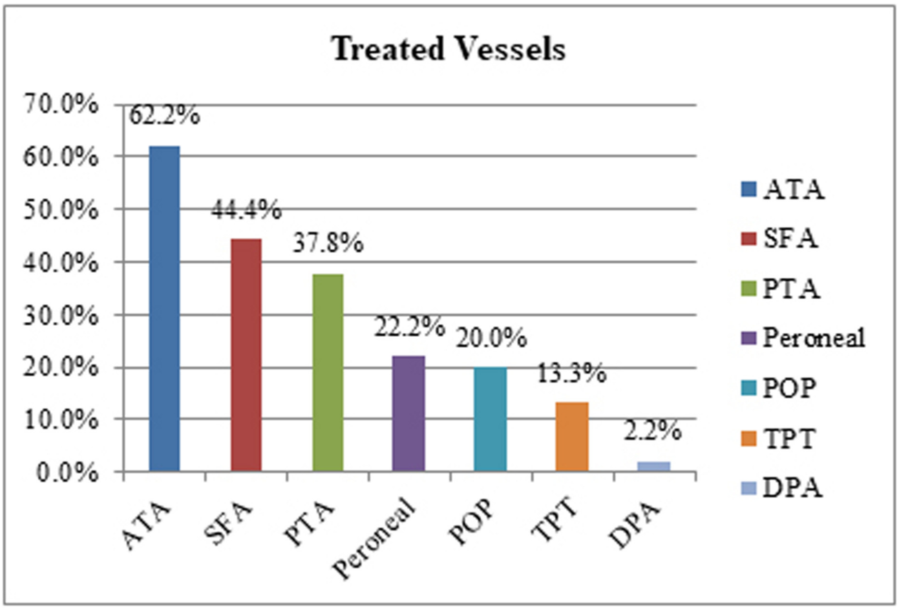
Duplex machine assessment was done for superficial femoral artery (SFA), popliteal, tibioperoneal trunk, ATA, DPA, PTA, and peroneal arteries to the manifested limb. Vessel was assessed at its proximal, mid, and distal third in a through screening, not a segmental one. The vessel was assessed with gray-scale and color mode to detect either there was a lesion or there was no lesion. If there was a lesion, the lesion was assessed for stenosis or occlusion, it was classified either less than 50% or more than 50% or more than 70% stenosis (Table 5).

All interventions were done under local anesthesia. The interventions were performed percutaneously via the CFA by an antegrade access. Access was ipsilateral in 25 (55.6%) of 45 patients and was contralateral in 20 (44.4%) of 45 patients. A 6-Fr sheath was used in 27 (60%) patients, whereas 8-Fr sheath in 17 (37.8%) patients. Regarding contrast, 39 (86.7%) patients were operated using dye, and only 6 patients were operated using CO_2.

A bolus of unfractionated heparin was administered at a dose of 70–100 IU/kg to achieve an activated clotting time of 250 s during the procedure. First, we did preliminary angiography to detect the site of lesion, distal runoff, and to compare it with the preoperative duplex US. This was followed by insertion of guidewire, balloons, and diagnostic and supporting catheters according to the type of lesion.

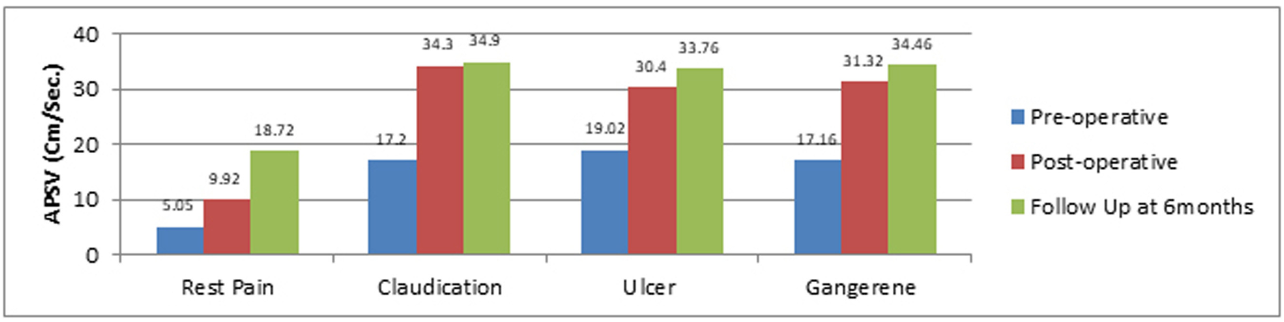
The subintimal channel was achieved by creating a 'Bolia loop' with half stiff J tip hydrophilic wire in four patients (8.9%). Once re-entry had been achieved and confirmed, the subintimal channel was immediately dilated with an appropriate balloon. Stenting was only used in cases of unsatisfactory hemodynamics on angiography. This was usually due to elastic recoil, significant stenosis of greater than 30%, or flow-limiting dissection. When stenting was required, we stented the entire subintimal channel including entry and re-entry points with self-expanding stents with the shortest possible lengths. Stent insertion was in 12 (26.6%) of 45 cases, whereas 33 (73.3%) of 45 cases did not need stents. SFA stenting was done in 11 (24.4%) of 45 cases, whereas popliteal stenting was done in one (0.022%) case only. There was no need to stent any tibials treated (Table 6).

Figure 1



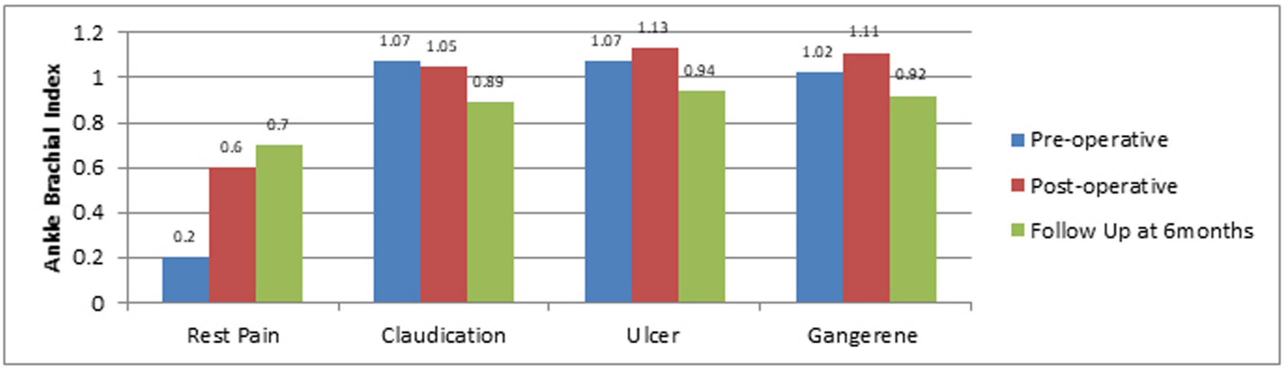
Treated Vessels.

Figure 2



Comparison between ankle peak systolic velocity in patients with rest pain, claudication, ulcer, and gangrene.

Figure 3



Comparison between ABI in patients with rest pain, claudication, ulcer and gangrene.

Table 1 Distribution of vascular surgery patients according to their demographic data such as age, sex, and side (*n*=45)

Demographic data	*n* (%)
Age group (years)	
40 to <60	16 (35.6)
60 to <70	20 (44.4)
≥70	9 (20.0)
Sex	
Female	13 (28.9)
Male	32 (71.1)

There were seven (15.6%) patients treated for femoropopliteal segment lesion, whereas 19 patients (42.2%) had been treated for tibial lesion and 19 patients (42.2%) had mixed disease (Table 7).

Figure 1 shows the distribution of target vessels. SFA was involved in 20 patients, popliteal in nine patients, tibioperoneal trunk in six patients, ATA in 28 patients, DPA in one patient, peroneal artery in 10 patients, and PTA in 17 patients.

The study was conducted on a wide duration of procedural time, ranging from 40 to 180 min (mean of 96.11±39.64 min). There were three (6.7%) patients complicated with hematoma at the access site following the procedure.

All patients who had intervention using either angioplasty with or without stenting were on double antiplatelet, clexane, vasodilators, and statins after intervention.

Technical success was achieved in 43 patients. Technical success was defined as successful crossing of the lesion with balloon dilatation resulting in less than 30% residual diameter reduction as assessed by quantitative intraprocedural angiography.

Table 2 Distribution of vascular surgery patients according to their risk factors (*n*=45)

Risk factors	*n* (%)
Current Smoking	19 (42.2)
Ex-smoker	9 (20.0)
Cigarettes 'packs' (day)	
1 packs	14 (31.1)
2 Packs	13 (28.9)
3 Packs	1 (2.2)
Obesity	
Normal weight <25	9 (20.0)
Obese 25 to <30	14 (31.1)
Overweight ≥30	22 (48.9)
DM	38 (84.4)
Type of DM	
I	3 (7.9)
II	35 (92.1)
HTN	22 (48.9)
Hypercholesterolemia	18 (40.0)
IHD	19 (42.2)
CHF	12 (26.7)
CVA	9 (20.0)
Hepatic	10 (22.2)
Renal insufficiency	13 (28.9)
Previous amputations	10 (22.2)

CHF, congestive heart failure; CVA, cerebrovascular accident; DM, diabetes mellitus; HTN, hypertension; IHD, ischemic heart disease.

A total of two patients had major and 18 patients had minor amputation, whereas 25 patients ended with no amputation. Mortality was recorded in one patient with pulmonary edema, which was beyond 30 days after procedure. Regarding overall mortality during the follow-up period, six (13.3%) patients died. Causes of mortality were different (stroke, myocardial infarction, covid-19 infection, and toxemia in a noncomplaint patient complicated with foot gangrene). Minor amputation of the foot included digital and ray amputation of the toe, transmetatarsal amputation of the forefoot, and Lisfranc and Chopart amputations of the mid foot. All of these preserve foot function. Major amputation is above these levels (Table 8).

The study was conducted on a wide healing duration ranging from 0 to 11 months (mean of 3.138±2.24 months), whereas clinical improvement for either rest

Table 3 Distribution of vascular surgery patients according to their clinical data (*n*=45)

Clinical data	*n* (%)
Rest pain	38 (84.4)
Ulcer	31 (68.9)
Gangrene	30 (66.7)
Popliteal pulse	21 (46.7)
Claudication	10 (22.2)

Table 4 Distribution of vascular surgery patients according to their classification standard (*n*=45)

Classification standard	*n* (%)
Rutherford classification	
3	3 (6.7)
4	5 (11.1)
5	37 (82.2)
Fontaine classification	
2b	2 (4.4)
3	6 (13.3)
4	37 (82.2)

Table 6 Distribution of vascular surgery patients according to their details of intervention regarding stent placement, stent size, stent site, drug eluting and subintimal (n=45)

	n (%)
Stent placement	12 (26.7)
Stent size	
No	33 (73.3)
4×20	2 (4.4)
5×20	5 (11.1)
6×15	1 (2.2)
6×20	3 (6.7)
6×8	1 (2.2)
Stent site	
No	33 (73.3)
SFA	11 (24.4)
POP	1 (2.2)
Drug eluting	1 (2.2)
Subintimal	4 (8.9)
Primary stent	
SFA	11 (24.4)
POP	1 (2.2)
Tibials	0

POP, popliteal artery; SFA, superficial femoral artery.

Table 5 Distribution of vascular surgery patients according to their lesion sites (*n*=45)

Lesion sites	No lesion [*n* (%)]	Stenosis <50% [*n* (%)]	Stenosis >50% [*n* (%)]	Stenosis >70% [*n* (%)]	Occluded [*n* (%)]
SFA					
Mid	23 (51.1)	1 (2.2)	3 (6.7)	5 (11.1)	13 (28.9)
Distal	37 (82.2)	0	1 (2.2)	5 (11.1)	2 (4.4)
Proximal	42 (93.3)	0	1 (2.2)	0	2 (4.4)
POP					
Mid	34 (75.6)	4 (8.9)	5 (11.1)	1 (2.2)	1 (2.2)
Distal	40 (88.9)	0	2 (4.4)	2 (4.4)	1 (2.2)
Proximal	42 (93.3)	0	2 (4.4)	0	1 (2.2)
TPT					
Mid	34 (75.6)	1 (2.2)	5 (11.1)	3 (6.7)	2 (4.4)
Distal	45 (100.0)	0	0	0	0
Proximal	45 (100.0)	0	0	0	0
ATA					
Mid	14 (31.1)	1 (2.2)	10 (22.2)	2 (4.4)	18 (40.0)
Distal	28 (62.2)	0	2 (4.4)	4 (8.9)	11 (24.4)
Proximal	24 (53.3)	0	5 (11.1)	5 (11.1)	11 (24.4)
DPA					
Mid	39 (86.7)	0	0	0	6 (13.3)
Distal	39 (86.7)	0	0	0	6 (13.3)
Proximal	39 (86.7)	0	0	0	6 (13.3)
PTA					
Mid	15 (33.3)	1 (2.2)	9 (20.0)	0	20 (44.4)
Distal	26 (57.8)	0	2 (4.4)	3 (6.7)	14 (31.1)
Proximal	25 (55.6)	0	4 (8.9)	2 (4.4)	14 (31.1)
Peroneal					
Mid	26 (57.8)	4 (8.9)	3 (6.7)	1 (2.2)	11 (24.4)
Distal	33 (73.3)	0	2 (4.4)	1 (2.2)	9 (20.0)
Proximal	35 (77.8)	1 (2.2)	2 (4.4)	0	7 (15.6)

ATA, anterior tibial artery; DPA, dorsalis pedis artery; POP, popliteal artery; PTA, posterior tibial artery; SFA, superficial femoral artery; TPT, tibioperoneal trunk.

pain or ulcer ranged from 1 to 25 months, with a mean of 5.34±4.43. Of 29 patients with ulcer, 23 patients healed. Only one case ended with amputation, whereas 38 patients survived. Limb salvage rate was 97.4% (Table 9).

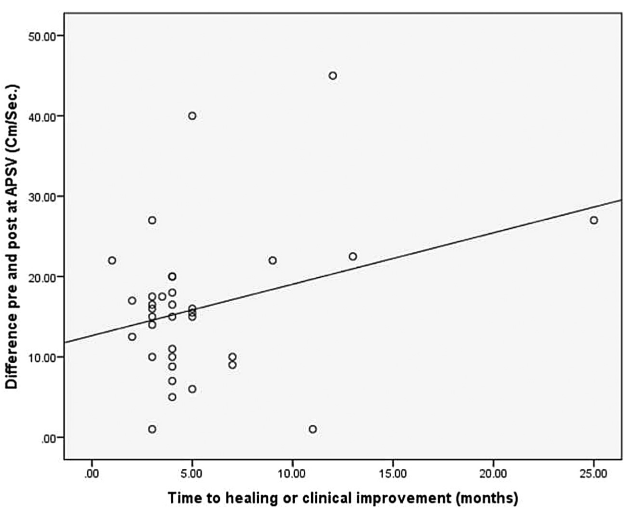
The study was conducted on a wide APSV (cm/s), ranging 0–55, with mean of 18.70±10.04 preoperatively, whereas postoperatively, it ranged from 4 to 70, with a mean of 31.50±16.60, and at 6-month follow-up ranged from 18 to 50, with a mean of 34.26 ±8.40. Regarding ABI, it ranged from 0 to 2.2, with a mean of 1.06±0.58 preoperatively, whereas postoperatively, it ranged from 0.357 to 2.51, with a mean of 1.12±0.38, and at 6-month follow-up, it ranged from 0.7 to 1.2, with a mean of 0.93±0.16 (Table 10).

There was a statistically significant increase in mean APSV (cm/s) at postoperatively and 6-month follow-up compared with preoperatively; this indicates improvement in the patients group using APSV (cm/s). Moreover, there was increase in APSV (cm/s) at 6-month follow-up compared with postoperative period (Mean diff. was 2.76±1.49, '8.8%'), but the difference was insignificant, with *P* value greater than 0.05 (Table 11).

Table 7 Distribution of vascular surgery patients according to their details of intervention regarding treated segmental lesions (*n*=45)

Treated segmental lesions	*n* (%)
Femoropopliteal	7 (15.6)
Tibials	19 (42.2)
Mixed disease	19 (42.2)

Figure 4



Scatter plot between difference in preoperative and postoperative results using ankle peak systolic velocity (cm/s) and time to healing or clinical improvement (months).

However, there was no statistically significant difference between mean ABI at postoperative and 6-month follow-up period compared with preoperative period; this indicates that the improvement is not apparent in the patient group using ABIs. However, there was decrease in mean ABI in 6-month follow-up period compared with

Table 8 Distribution of vascular surgery patients according to their amputation, procedure-related mortality, and overall mortality (*n*=45)

	n (%)
Amputation	
Major amputation	2 (4.4)
Minor amputation	18 (40.0)
No amputation	25 (55.6)
Procedure-related mortality	
Died	1 (2.2)
Alive	44 (97.8)
Overall mortality	
Died	6 (13.3)
Alive	39 (86.7)

Table 9 Distribution of vascular surgery patients according to their procedure regarding ulcer healing, limb salvage, healing duration, and time to healing or clinical improvement (*n*=45)

Procedure	Total (*n*=39) [*n* (%)]
Ulcer healing	
Non healing	6 (15.4)
Healing	23 (59.0)
No ulcer	10 (25.6)
Ulcer healing in relation to ulcerated patients (*n*=29)	
Healed	23 (79.3)
Nonhealed	6 (20.7)
Limb salvage	
Amputation	1 (2.6)
No amputation	38 (97.4)
Healing duration (months)	
Range	0–11
Mean±SD	3.13±2.24
Time to healing or clinical improvement (months)	
Range	1–25
Mean±SD	5.34±4.43

Table 10 Distribution of vascular surgery patients according to their APSV (Cm/Sec.) and ABIs (*n*=45)

	Range	Mean±SD
APSV (cm/s)		
Preoperative	0–55	18.70±10.04
Postoperative	4–70	31.50±16.60
Follow-up at 6 months	18–50	34.26±8.40
ABIs		
Preoperative	0–2.2	1.06±0.58
Postoperative	0.357–2.51	1.12±0.38
Follow-up at 6 months	0.7–1.2	0.93±0.16

ABI, ankle brachial index; APSV, ankle peak systolic velocity.

postoperative period (mean difference was −0.09±0.05, −8.04%). There was no statistically significant difference, with *P* value greater than 0.05 (Table 12).

There was a positive correlation between the improvement in APSV and improvement in rest pain (mean 5.05±9.03 before intervention vs. 9.92 ±17.65 after intervention), whereas mean ABI was 0.20±0.40 before intervention vs. 0.60±0.40 after intervention.

There was a significant improvement in APSV comparing preintervention and postintervention results in claudicants (mean 17.20±6.99 before vs. 34.30±15.09 after intervention), whereas mean ABI was 1.07±0.67 before vs. 1.05±0.21 after intervention.

However, among those with ulcer, mean±SD APSV before intervention was about 19.02±11.64 and about 30.40±16.71 after intervention. Mean±SD ABI before intervention was about 1.07±0.59 and 1.13±0.41 after intervention (Figures 2 and 4).

There was a positive correlation between the postintervention improvement in APSV and rate of ulcer healing, but a negative correlation for the ABI (mean 1.02±0.60 vs. 1.11±0.42). (Fig 3).

Table 11 Comparison between APSV preoperative, postoperative, and on follow-up at 6 months

Ankle peak systolic velocity (cm/s)	Range	Mean±SD	Paired sample *t* test			
			MD±SE	Change%	*t* test	*P* value
Preoperative	0–55	18.70±8.04				
Postoperative	4–70	31.50±12.60	12.80±2.40	68.50%	−5.320	<0.001**
Follow-up at 6 months	18–50	34.26±8.40	15.56±1.60	83.20%	−9.736	<0.001**

APSV, ankle peak systolic velocity.

Table 12 Comparison between ABI preoperative, postoperative, and on follow-up at 6 months

Ankle brachial index	Range	Mean±SD	Paired sample *t* test			
			MD±SE	Change%	*t* test	*P* value
Preoperative	0–2.2	1.06±0.58				
Postoperative	0.357–2.51	1.12±0.38	0.06±0.09	5.70%	−0.725	0.473
Follow-up at 6 months	0.7–2.2	1.03±0.16	−0.03±0.06	−2.83%	0.334	0.739

ABI, ankle brachial index.

Table 13 Comparison between non-DM and DM according to APSV and ABI

	No DM (*n*=35)	DM (*n*=10)	*Z* test	*P* value
APSV (cm/s)				
Preoperative	10.86±8.18	20.14±9.76	−2.383	0.017*
Postoperative	29.36±17.93	31.89±16.57	−0.455	0.649
Follow-up at 6 months	31.00±9.68	34.97±8.09	−1.205	0.228
Ankle brachial index				
Preoperative	1.02±0.70	1.06±0.57	−0.173	0.863
Postoperative	1.16±0.48	1.11±0.36	−0.317	0.751
Follow-up at 6 months	0.99±0.22	0.92±0.14	−0.808	0.419

ABI, ankle brachial index; APSV, ankle peak systolic velocity; DM, diabetes mellitus; *Z*, Mann–Whitney test.

Table 14 Comparison between nonrenal insufficiency and renal insufficiency according to APSV and ABI

	No renal insufficiency (*n*=35)	Renal insufficiency (*n*=10)	*Z* test	*P* value
APSV (cm/s)				
Preoperative	19.52±10.85	16.68±7.72	−0.527	0.598
Postoperative	30.72±17.49	33.42±14.64	−0.615	0.538
Follow-up at 6 months	34.38±8.86	33.90±7.31	−0.342	0.732
Ankle brachial index				
Preoperative	1.13±0.54	0.88±0.66	−1.355	0.176
Postoperative	1.11±0.34	1.15±0.46	−0.140	0.889
Follow-up at 6 months	0.96±0.16	0.85±0.14	−1.928	0.054

ABI, ankle brachial index; APSV, ankle peak systolic velocity; *Z*, Mann–Whitney test. *P*>0.05, NS.

Table 15 Comparison between ulcer healing according to APSV and ABI in follow-up at 6 months

Follow-up at 6 months	Healing (*n*=23)	Non healing (*n*=6)	No ulcer (*n*=10)	ANOVA	*P* value
APSV (cm/s)	36.52±8.14	29.83±11.25	31.70±5.66	2.276	0.117
ABIs	0.93±0.17	0.97±0.16	0.90±0.15	0.324	0.725

This table shows no statistically significant difference between ulcer healing according to APSV and ABI in follow up at 6 months. ABI, ankle brachial index; ANOVA, one way analysis of variance; APSV, ankle peak systolic velocity. $P>0.05$, NS.

Table 16 Correlation between difference in preoperative and postoperative results using APSV (cm/s), as well as difference in preoperative

	Time to healing or clinical improvement (months)	
	r	*P* value
Difference in preoperative and postoperative results using APSV (cm/s)	0.407	0.038*
Difference in preoperative and postoperative results using ABIs	0.245	0.163

APSV, ankle peak systolic velocity; *r*, Pearson correlation coefficient; S, significant. $P>0.05$, NS. *$P<0.05$, S.

Moreover, there was a statistically significant difference between non-DM and DM, in favor of DM, according to APSV at preoperative period, whereas the rest of the periods had insignificant difference (Table 13).

There was no statistically significant difference in APSV and ABI comparing patients with renal insufficiency and those with unimpaired kidney function (Table 14).

There was a statistically significant positive correlation comparing difference in preoperative and postoperative results using APSV (cm/s) with time to healing or clinical improvement (months). APSV increase indicates clinical improvement, and on following up of the patients, it showed increase with decrease in healing duration (Tables 15 and 16, and Fig 3).

Discussion

Wilson and colleagues reported a significant increase in duplex ultrasound-derived mean PSVs in the AT, PT, and peroneal arteries in comparing mean PSVs before and after endovascular intervention. The average percentage increase of the AT, PT, and peroneal mean PSVs after intervention were 110, 117, and 92%, respectively [8].

In this study, APSV increased by 86.50% after intervention, and the effect remained at 6 months. It shows also a significant increase at 6-month follow-up following intervention.

In the study by Pardo and colleagues, absolute ankle pressure, ABI, and arteriography could not establish differences from normal values because they could not predict hemodynamic supply demand. This may be the key reason ABI does not always reliably predict the magnitude of the CLI [9].

Regarding ABI, there was no statistically significant difference when comparing mean ABI postoperatively and 6-month follow-up with preoperative ABI; this indicates that improvement is not apparent in patient groups through ABIs, whereas there was decreased mean ABI at 6-month follow-up compared with postoperative period in our study.

In the study by Manuel Pardo and colleagues, after PTA, vessel stenosis decreased from 58.33±20.07 to 21.87 ±13.57% ($P<0.001$) and ABI increased from 0.79 ±0.57 to 0.95±0.47 ($P<0.001$). ABI was not measurable in 25 limbs (23.36%, 25/107) because of the absence of both tibial signals in 10 patients (9.34%, 10/107) or the presence of arterial calcifications in 15 (14.02%, 15/107). After PTA, ABI was not measurable in 17 patients (15.90%, 17/107) because of the absence of an arterial signal in three (2.80%, 3/107) or the presence of arterial calcifications in 14 (13.08%, 14/107) [10].

In the study by Wasfy and colleagues, all of the limbs with severe ischemia (ABI ≤0.4) had APSV less than or equal to 25 cm/s, and all of the limbs with mild to moderate ischemia (ABI >0.4 to <1) had APSV greater than 25 cm/s but less than 75 cm/s, whereas all of healthy volunteers with no ischemia (ABI≥1, and palpable pedal pulses) had APSV greater than or equal to 75 cm/s [1].In the study by de Vinuesa and colleagues there is a strong association between diabetes and medial artery calcification (MAC). This condition causes arterial wall stiffness, which results in high pressure ankle, and so high ABI. MAC is often associated with peripheral neuropathy and chronic renal failure. In addition, an ABI greater than 1.3 in chronic renal failure (CRF) is frequently associated with hyperparathyroidism, suggesting a possible role of disturbances in calcium and phosphorus metabolism in occurrence of MAC [11].

In this study, patients with DM, mean±SD APSV before intervention was 20.14±9.76 and mean±SD ABI before intervention was 1.06±0.57. After intervention, APSV represented as 31.89±16.57 and ABI represented as 1.11 ±0.36. In the 6-month follow-up, APSV represented as 34.97±8.09 and ABI represented as 0.92±0.14.

In the study by Silvestro *et al.* [12], the presence of noncompressible tibial vessels associated with accelerated atherosclerosis, diabetes, and chronic renal insufficiency. ABI was not changed after angioplasty or in following up of patients.

In this study, among patients with renal insufficiency, mean±SD APSV before intervention was 16.68±7.72 and mean±SD ABI before intervention was 0.88±0.66. After intervention, APSV represented as 33.42±14.64 and ABI represented as 0.84±0.46. At 6-month follow-up, APSV represented as 33.90±7.31 ABI represented as 0.85±0.14.

In the study by Herzallah [13], at a cutoff value of 37.5 cm/s, the APSV was found to show a sensitivity of 90.5% (95% confidence interval: 84.3–98.1%), a specificity of 94.2% (95% confidence interval: 77.3–96%), a positive predictive value of 90.5%, and negative predictive value of 94.2% in predicting nonhealing of diabetic foot lesions.

In this study, among patients with healing ulcer, mean ±SD APSV was 36.52±8.14 and mean±SD ABI was 0.93±0.17.

Limitations

The relatively small number of limbs studied and that a new parameter (APSV) was used for investigating its value in predicting wound nonhealing, angiographic, and clinical success were the limitation of the study. Larger studies by other groups are suggested.

Conclusion

APSV is an attractive arterial flow measure. This fast and simple functional measurement can be a valuable addition to duplex examination to objectively quantify vascular status following infrainguinal arterial angioplasty. APSV could predict healing of lesions of patients with CLI with high degree of accuracy. It can be used as alternative parameter to ABI in following up patients after infrainguinal arterial angioplasty, especially in the presence of arterial calcification.

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Conflicts of interest

There are no conflicts of interest.

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