Original Article

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Correlations Between the Ankle-Brachial Index, Percentage of Mean Arterial Pressure, and Upstroke Time for Endovascular Treatment

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Abstract

Background: The ankle-brachial index (ABI), percentage of mean arterial pressure (%MAP), and upstroke time (UT) are indicators to diagnose lower-extremity peripheral artery disease (PAD). However, the respective relationship between these parameters is unknown. In this study, we analyzed the correlations between ABI, %MAP, and UT and examined their clinical usefulness for endovascular treatment (EVT).

Methods: Sixty-three consecutive subjects who underwent successful EVT for aortoiliac to femoropopliteal artery diseases were analyzed. The ABI, %MAP, and UT were measured using an automated oscillometric device.

Results: There were significant correlations between the ABI and %MAP (r = -0.425, P < 0.001), the ABI and UT (r = -0.304, P = 0.017), and %MAP and UT (r = 0.368, P = 0.003). In terms of lesion length, there was a significant difference in %MAP after EVT (focal, 42.6%; short, 44.5%; intermediate, 47.1%; long, 49.1%; P = 0.015). There was minimal %MAP improvement in the case of a long lesion length (focal, -8.83%; short, -5.10%; intermediate, -3.00%; long, -1.50%; P = 0.006). Excessive lesion calcification also hindered %MAP improvement (grade 0, -7.16%; grade 1, -5.52%; grade 2, -4.71%; grade 3, -2.80%; grade 4, -1.00%; P = 0.049). Patients who underwent re-EVT (an average of 10.1 months after initial EVT) had minimal %MAP improvement (-2.76% vs. -5.95%, P = 0.035) at the first outpatient visit (an average of 3.3 weeks after EVT).

Conclusions: In conclusion, the ABI, %MAP, and UT are correlated with each other. If the length of the lesion is long and there is excessive calcification, %MAP improvement is minimal. Moreover, minimal %MAP improvement may be an indicator of future restenosis.

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Keywords: Ankle-brachial index; Percentage of mean arterial pressure; Upstroke time; Endovascular treatment; Calcification

Introduction

Lower-extremity peripheral artery disease (PAD) is the third leading cause of atherosclerotic cardiovascular morbidity, following coronary artery disease and stroke [1]. A quantitative assessment of lower-limb atherosclerosis is important for the diagnosis of existing PAD [2]. The ankle-brachial index (ABI) is the ratio of the systolic blood pressure measured at the ankle to that measured at the brachial artery. An ABI ≤ 0.90 should be considered the threshold for confirming the diagnosis of lower-extremity PAD [3-7]. The ABI is an indicator of atherosclerosis at other vascular sites and can serve as a prognostic marker for cardiovascular events and functional impairment, even in the absence of PAD symptoms [8, 9]. It is also an indicator of the therapeutic effect of endovascular treatment (EVT) [10].

The percentage of mean arterial pressure (%MAP) is the height of the mean area of the arterial wave divided by the peak amplitude [11, 12]. The upstroke time (UT) indicates the time interval between the onset and peak of a pulse volume wave [13]. According to the guidelines of the Japan Circulation Society on using non-invasive vascular function testing to detect patients with PAD, the cut-off values are 45% and 180 ms for %MAP and UT, respectively [14].

A combination of ABI, %MAP, and UT is necessary to increase the diagnostic accuracy for PAD, particularly for mild arterial stenosis [11, 15]. However, the relationships between these parameters as well as their clinical implications, except for PAD diagnosis, are unknown. In this study, we analyzed the correlations between ABI, %MAP, and UT and examined their clinical usefulness for EVT.

Materials and Methods

A total of 63 consecutive Japanese patients (mean age, 73.3 years; 24% women) who underwent successful EVT for aortoiliac to femoropopliteal artery disease at the Japan Community Healthcare Organization Osaka Hospital (Osaka, Japan)

Table 1. Patient Characteristics (N = 63)

Demographic	
Age, years	73.3 ± 7.6
Male/female	48 (76%)/15 (24%)
Height, m	1.61 ± 0.09
Weight, kg	61.3 ± 13.2
BMI, kg/m^2	23.6 ± 4.4
Medical history	
HT	52 (83%)
DM (type 2)	39 (62%)
DL	41 (65%)
IHD	32 (51%)
HD	17 (27%)
AF	7 (11%)
Current/past smoking	40 (63%)/6 (10%)
Laboratory characteristics	
TC, mg/dL	180 ± 38
HDL-C, mg/dL	52 ± 15
LDL-C, mg/dL	103 ± 31
TG, mg/dL	150 ± 68
HbA1c, %	6.5 ± 0.9
BG, mg/dL	135 ± 42
CRP, mg/dL	0.57 ± 1.37
Clinical presentation	
Fontaine stage: 2/3/4	45 (71%)/3 (5%)/15 (24%)
Rutherford category: 2/3/4/5/6	35 (56%)/10 (16%)/3 (5%)/11 (17%)/4 (6%)
ABI	0.66 ± 0.12
%MAP, %	49.9 ± 4.7
UT, ms	224 ± 51

Data are expressed as the mean ± SD or number (%). BMI: body mass index; HT: hypertension; DM: diabetes mellitus; DL: dyslipidemia; IHD: ischemic heart disease; HD: hemodialysis; AF: atrial fibrillation; TC: total cholesterol; HDL-C: high-density lipoprotein cholesterol; LDL-C: low-density lipoprotein cholesterol; TG: triglyceride; HbA1c: glycated hemoglobin; BG: blood glucose; CRP: C-reactive protein; ABI: ankle-brachial index; %MAP: percentage of mean arterial pressure; UT: upstroke time.

between January 2017 and December 2018 were included in this study. Patients with acute thrombosis, in-stent restenosis, unavailable ABI data, and surgical bypass graft surgery were excluded. In addition, patients who did not show post-EVT improvements in the ABI and/or angiographic stenosis were excluded.

The ABI data were obtained using an automated oscillometric device (VP-1000; Omron Healthcare Co., Kyoto, Japan). This device also automatically calculates the %MAP and UT from the pulse volume wave. The lesion length was classified as follows: focal, ≤ 1 cm; short, > 1 and < 5 cm; intermediate, ≥ 5 and < 15 cm; and long, ≥ 15 cm [16]. The extent of lesion calcification was classified according to the peripheral arterial calcium scoring system (PACSS; grade 0, no visible calcification; grade 1, unilateral calcification, < 5 cm; grade 2, unilateral calcification, ≥ 5 cm; grade 3, bilateral calcification, < 5 cm; and grade 4, bilateral calcification, ≥ 5 cm) [17].

Statistical analyses were performed using EZR [18]. The data are expressed as mean ± standard deviation or number (%). The continuous variables were compared using an analysis of variance or a Student's *t*-test. P values of < 0.05 were considered statistically significant. The study was approved by the Institutional Review Board of Japan Community Healthcare Organization Osaka Hospital. This study was conducted in compliance with the ethical standards of the responsible institution on human subjects as well as with the Helsinki Declaration.

Results

The patient characteristics are summarized in Table 1. Patients undergoing hemodialysis were accounted for 27% of all pa-

Table 2. Lesion Characteristics (N = 63)

Lesions	
CIA	12 (19%)
EIA	5 (8%)
TASCII A/B/C/D	7/7/2/1
CFA	2 (3%)
SFA	43 (68%)
POP	1 (2%)
TASCII A/B/C/D	4/20/15/7
Lesion length	
Focal, ≤ 1 cm	6 (10%)
Short, > 1 and < 5 cm	29 (46%)
Intermediate, ≥ 5 and < 15 cm	19 (30%)
Long, ≥ 15 cm	9 (14%)
PACSS grade	
0	6 (10%)
1	21 (33%)
2	14 (22%)
3	16 (25%)
4	6 (10%)
Stenosis	
75%	4 (6%)
90%	30 (48%)
99%	8 (13%)
100%	21 (33%)
Procedure	
POBA	28 (44%)
DCB	5 (8%)
Stent	27 (43%)
Viabahn® stent graft	3 (5%)

CIA: common iliac artery; EIA: external iliac artery; CFA: common femoral artery; SFA: superficial femoral artery; POP: popliteal artery; TASCII: Trans-Atlantic Inter-Society Consensus II; PACSS: peripheral arterial calcium scoring system; POBA: plain old balloon angioplasty; DCB: drug-coated balloon.

tients, and current smokers accounted for 63% of all patients. The mean ABI, %MAP, and UT before EVT were 0.66 ± 0.12, 49.9±4.7%, and 224 ± 51 ms, respectively. The lesion characteristics are summarized in Table 2. Before EVT, there were significant correlations between the ABI and %MAP (r = -0.425, P < 0.001), the ABI and UT (r = -0.304, P = 0.017), and the %MAP and UT (r = 0.368, P = 0.003) (Fig. 1a-c). The mean ABI, %MAP, and UT had improved 1 day after EVT (0.92 ± 0.17, 45.8±4.9%, and 189 ± 36 ms, respectively) (Fig. 2a-c). Compared to the pre-EVT correlations, the correlations were stronger 1 day after EVT (ABI vs. %MAP, r = -0.502, P < 0.001; ABI vs. UT, r = -0.317, P = 0.011; %MAP vs. UT, r = 0.701; P < 0.001) (Fig. 3a-c). In terms of lesion length, there was no difference in %MAP values before EVT; however, there was a significant difference after EVT (focal, 42.6±3.98%; short, 44.5±4.99%; intermediate, 47.1±4.48%; long, 49.1±3.65%; P = 0.015) (Fig. 4a, b). Although the extent of improvement in the ABI and UT did not differ according to the lesion length, the improvement in the %MAP was minimal in the case of a long lesion length (focal, -8.83±4.40%; short, -5.10±4.60%; intermediate, -3.00±3.85%; long, -1.50±2.39%; P = 0.006) (Fig. 4c). There was minimal %MAP improvement in the case of excessive lesion calcification (grade 0, -7.16±4.21%; grade 1, -5.52±4.17%; grade 2, -4.71±3.49%; grade 3, -2.80±4.64%; grade 4, -1.00±2.91%; P = 0.049) (Fig. 4d).

At the time of the first outpatient visit (i.e., an average of 3.3 weeks after EVT), patients who underwent re-EVT (n = 15, an average of 10.1 months after initial EVT) showed minimal %MAP improvement compared to patients who did not undergo re-EVT (-2.76±3.65% vs. -5.95±4.86%, P = 0.035) (Fig. 5).

Discussion

The number of patients with PAD may not accurately reflect the true burden because the sensitivity of an ABI < 0.90 in the detection of an atheroma in a leg artery is likely to be < 80% [1]. Arterial stenosis elevates %MAP and UT determined from pulse waves, and the normal levels of %MAP and UT are 45% and 180 ms, respectively [14]. Consideration of the ABI and %MAP improves diagnostic sensitivity for PAD. In a previous study, the frequency of accurate diagnoses based on ABI, %MAP, and UT data (ABI < 1.00, %MAP ≥ 45%, and UT ≥ 180 ms) was higher than that solely based on ABI < 1.00 [15]. In another study, using a combination of ABI and %MAP data (ABI < 0.90 and %MAP ≥ 42.5%) resulted in higher sensitivity and specificity for PAD diagnosis than the use of criteria for a low (≤ 0.90) or borderline (0.91 - 0.99) ABI [11].

However, the number of reports on the respective relationships between ABI, %MAP, and UT are limited [19]. Therefore, this study aimed to investigate the relationships between these parameters as well as the implications of their utility for EVT. In this study, the ABI and %MAP, the ABI and UT, and the %MAP and UT were correlated before EVT. Moreover, at 1 day post-EVT, these correlations were stronger than those before EVT. This finding suggests that each of these three parameters is complementary and effective to diagnose PAD. Previous reports have shown that these parameters effectively facilitate PAD diagnosis, and our results confirm this [11, 15].

This study also revealed that even after successful EVT, the extent of improvement in %MAP will be minimal if the length of the lesion is relatively long. This finding provides new insight into the implications of %MAP. No studies have reported that %MAP has any value other than being an auxiliary diagnostic indicator of PAD. Moreover, the extent of %MAP improvement depends on the extent of lesion calcification, evaluated according to the PACSS. This finding is necessary to understand the characteristics of %MAP. Because %MAP includes the area and amplitude of the arterial wave as parameters, its sensitivity may be relatively high compared to that of the ABI, which only takes into account pressure. Excessive arterial calcification is likely to result in a pseudo-normal-

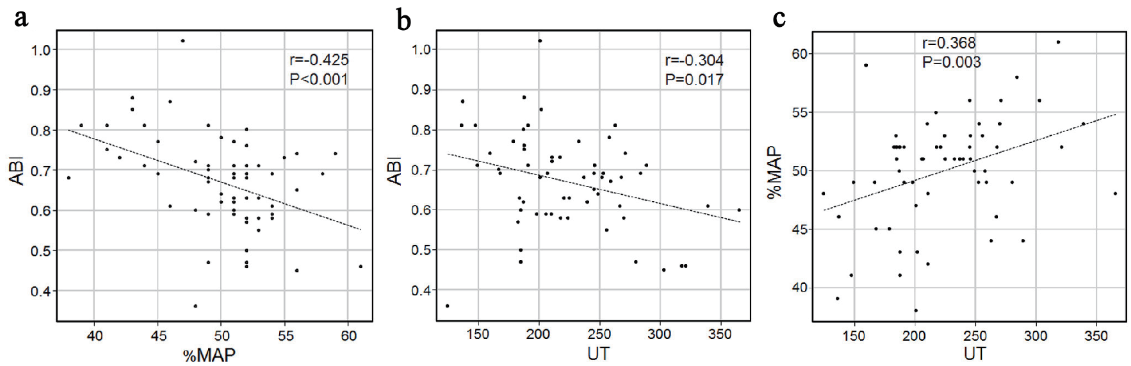

Figure 1. Pre-EVT scatter plots. (a) The ABI and %MAP; (b) The ABI and UT; and (c) The %MAP and UT. EVT: endovascular treatment; ABI: ankle-brachial index; %MAP: percentage of mean arterial pressure; UT: upstroke time

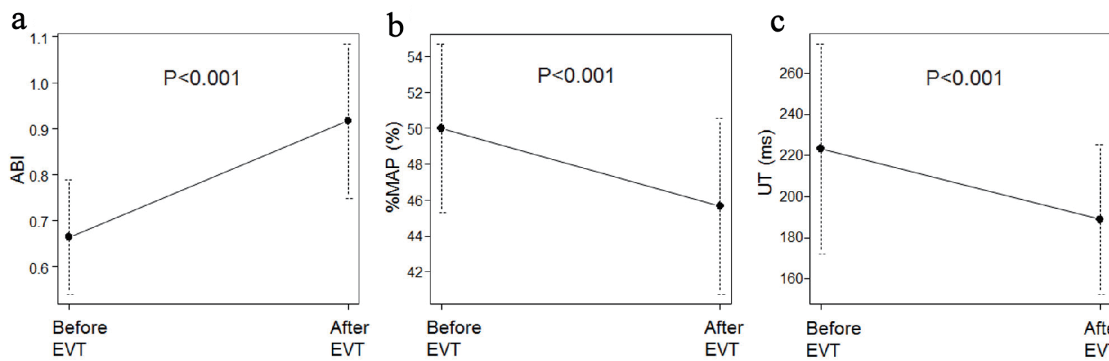

Figure 2. (a) The ABI before and after EVT. (b) The %MAP before and after EVT. (c) The UT before and after EVT. ABI: ankle-brachial index; %MAP: percentage of mean arterial pressure; UT: upstroke time; EVT: endovascular treatment.

ized ABI [20]. Therefore, if there is minimal %MAP improvement, even when the ABI has appeared to improve under the condition of excessively calcified lesions, patients should be carefully monitored after successful EVT.

This study also revealed that at the time of the first outpatient visit (i.e., an average of 3.3 weeks after EVT), patients who underwent re-EVT (an average of 10.1 months after EVT) had minimal %MAP improvement compared to patients who did not undergo re-EVT. To date, %MAP has been used to diagnose PAD; however, there is no report on using it to predict disease progression after EVT. Previously, researchers have reported that lesion length is an independent predictor of in-stent restenosis [21, 22]. In this study, we revealed that %MAP improvement is dependent on the target lesion length and extent of calcification. However, even if the length of the lesion is long, it may be predicted that restenosis is not likely to occur in the patients with significant %MAP improvement. Conversely, even if EVT is successful and the ABI improves, if %MAP

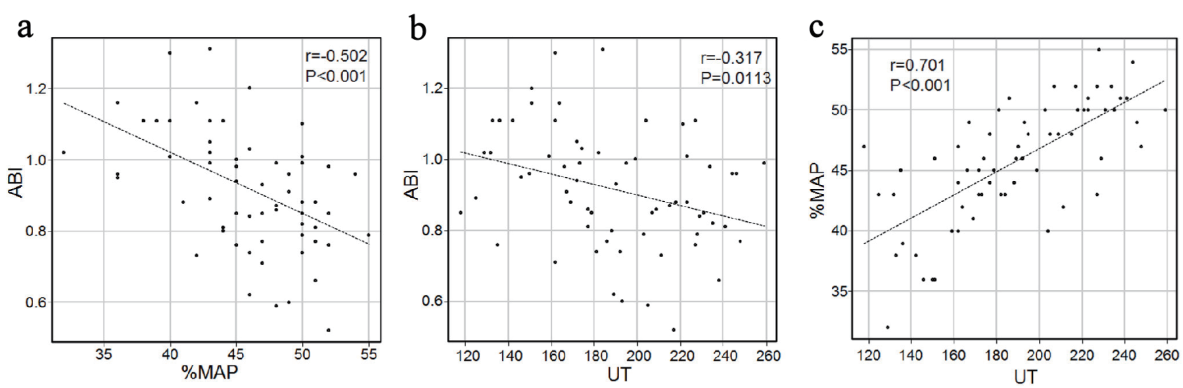

Figure 3. One day post-EVT scatter plots. (a) The ABI and %MAP; (b) The ABI and UT; and (c) The %MAP and UT. EVT: endovascular treatment; ABI: ankle-brachial index; %MAP: percentage of mean arterial pressure; UT: upstroke time.

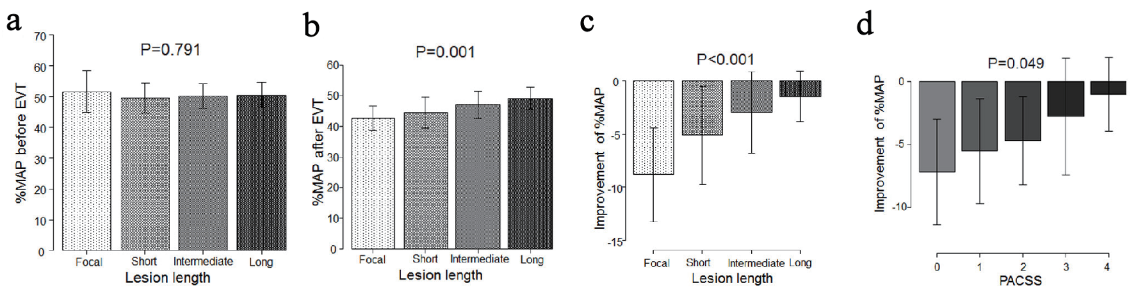

Figure 4. (a) Pre-EVT relationship between %MAP and lesion length. (b) One day post-EVT relationship between %MAP and lesion length. (c) %MAP improvement according to the lesion length before and after EVT. (d) %MAP improvement according to the PACSS before and after EVT. %MAP: percentage of mean arterial pressure; EVT: endovascular treatment; PACSS: peripheral arterial calcium scoring system.

does not improve, restenosis of the target lesion will eventually occur. Further research is needed to validate these results.

Limitations

Several limitations of this study must be acknowledged. First, there was a selection bias because this article was a retrospective study conducted in a single hospital. Second, the number of patients included in this study was small, and the follow-up period for restenosis was limited. Third, patients with excessively low ABI values were excluded from this study. Thus, patients with severe lower-limb blood flow impairment were not included in this study.

Conclusions

The ABI, %MAP, and UT are correlated with each other. If the target lesion length is long and there is excessive calcification, the extent of %MAP improvement may be small. Additionally, minimal %MAP improvement after EVT may predict future restenosis.

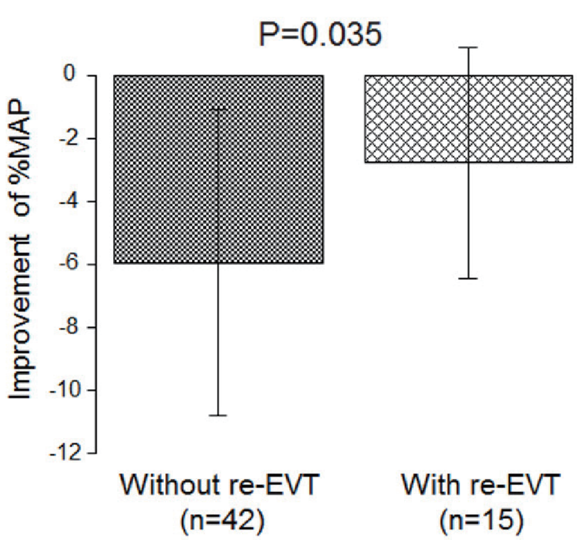

Figure 5. Comparison of the %MAP improvement between the patients who underwent re-EVT and those who did not undergo re-EVT (at the time of the first outpatient visit). %MAP: percentage of mean arterial pressure; EVT: endovascular treatment.

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Financial Disclosure

None to declare.

Conflict of Interest

The authors report no financial relationships or conflicts of interest regarding the content herein.

Informed Consent

All patients provided written informed consent.

Author Contributions

All authors contributed to data acquisition and analysis.

Data Availability

Any inquiries regarding supporting data availability of this study should be directed to the corresponding author.

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