CLINICAL STUDY

Evaluation of Distal Hemodynamic Changes of Lower Extremity after Endovascular Treatment: Correlation between Measurements of Color-Coded Quantitative Digital Subtraction Angiography and Ankle-Brachial Index

Wen-Sheng Lou, MD, Hao-Bo Su, MD, Kai-Yi Huang, Dipl.-Ing., Xu He, MD, Liang Chen, MD, Guo-Ping Chen, MD, Wan-Yin Shi, MD, Jing-Feng Han, PhD, and Jian-Ping Gu, MD

ABSTRACT

Purpose: To confirm the feasibility of using time-to-peak (TTP) measurements derived from color-coded digital subtraction angiography (ccDSA) imaging to assess improvements in distal circulation in relation to the ankle-brachial index (ABI).

Materials and Methods: Nineteen patients who underwent percutaneous transluminal angioplasty and/or stent placement (in 20 lower extremities) were evaluated. A region of interest (ROI) at the proximal superficial femoral artery (SFA) was selected for a reference TTP for quantitative assessments. The ROI measurements of the TTP interval between medial and lateral plantar/dorsalis pedis relative to the reference was regarded as the ΔTTP and used to assess distal hemodynamic improvement achieved by the revascularization. The ABI was obtained with a handheld Doppler ultrasound machine with a manually operated blood-pressure cuff. Correlation between the two methods was analyzed.

Results: The ABI improved significantly from 0.44 ± 0.18 to 0.79 ± 0.20 ($t = 10.11$; $P < .0001$) after the intervention. TTP, which reflected the blood flow time from the proximal SFA to the foot, became much faster, from 11.86 seconds ± 4.26 to 6.75 seconds ± 2.03 ($t = 6.57$; $P < .001$). A good correlation was observed between the improvement ratios of ΔTTP and ABI ($r = 0.863$).

Conclusions: TTP measurements derived from ccDSA provide an easy and objective method for assessment of distal hemodynamic changes after endovascular treatment of lower-extremity peripheral arterial disease (PAD). It may provide a quantitative method to assess the adequacy of endovascular interventions and provide more objective suggestions for procedure endpoints, with potentially better clinical outcomes for patients with PAD.

ABBREVIATIONS

ABI = ankle-brachial index, ccDSA = color-coded digital subtraction angiography, CFA = common femoral artery, DP = dorsalis pedis, DSA = digital subtraction angiography, FOV = field of view, PAD = peripheral arterial disease, PTA = percutaneous transluminal angioplasty, ROI = region of interest, SFA = superficial femoral artery, TTP = time to peak

Peripheral arterial disease (PAD) of the lower extremities is a common circulation problem that occurs between 4.5% and 29% of people worldwide and affects more than 20% of individuals older than 75 years old (1,2). PAD is characterized by stenosis/occlusion of the affected arteries; therefore, restoration of patency and reconstitution of blood flow have become the fundamental aspects of endovascular treatments for PAD. Determining the endpoint of varied endovascular procedures to optimize clinical outcomes is very important.

From the Department of Interventional Radiology (W.-S.L., H.-B.S., X.H., L.C., G.-P.C., W.-Y.S., J.-P.G.), Nanjing First Hospital, Nanjing Medical University, No.68, Changle Rd., Nanjing 210006, China; and Clinical Research Collaboration (K.-Y.H., J.-F.H.), Siemens Ltd., China Shanghai Branch, Shanghai, China. Received August 24, 2015; final revision received February 7, 2016; accepted February 10, 2016. **Address correspondence to** J.-P.G.; E-mail: cjr.gujianping@vip.163.com

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Currently, the indices of patency or residual stenosis as revealed by conventional angiography are widely used to evaluate the adequacy of the treatments. However, these evaluations are primarily dependent on the anatomic and morphologic responses of the diseased arteries to the treatments visualized by conventional digital subtraction angiography (DSA). Consequently, these the evaluations rely largely on the operator's experience and occasionally seem to be biased. The advent of color-coded DSA (ccDSA) offered an easy and simple approach to the quantification of distal hemodynamic changes following the endovascular treatment (3–5). Without additional radiation exposure or contrast media, the postprocessing of conventional DSA to ccDSA provides additional parameters, including the morphologic responses of the treated arteries and the hemodynamic changes. Therefore, in the present study, we examined whether the combination of immediate conventional angiography and ccDSA was able to predict outcomes and evaluate the adequacy of treatment more objectively and precisely.

The ankle-brachial index (ABI) is a widely accepted parameter for assessment of the severity of PAD because it is simple and reliable. An increase in postoperative ABI may also predict a favorable outcome of endovascular treatment. However, ABI measurements are typically performed a few days after intervention, and there are no current validated methods for the immediate assessment of the adequacy of endovascular intervention while the patient is still on the table. ccDSA could potentially address the unmet need for an immediate assessment of the hemodynamic changes, and therefore represents an additional tool for flow assessment in addition to ABI. The goal of the present study was to evaluate the feasibility of the application of ccDSA in patients with PAD and assess distal hemodynamic improvements in diseased arteries following endovascular treatment by using ccDSA.

MATERIALS AND METHODS

Patients

The present retrospective study was approved by the institutional ethical committee. Written informed consent for the procedure was obtained from all patients.

A total of 23 consecutive patients with PAD referred for endovascular treatments between March 2013 and April 2014 were screened for evaluation in this single-center study. Four patients were excluded as a result of evident motion artifacts during DSA acquisition. Twenty lower limbs of 19 patients (median age, 72 y; 47.4% male patients) were included in the data analysis.

The clinical criterion for study entry was symptomatic PAD ranging from moderate intermittent claudication (Rutherford category 2) to severe ischemic ulcers or frank gangrene (Rutherford category 6) (6). The anatomic inclusion criterion was confirmed by computed tomographic (CT) angiography with stenosis of more than 50% or occlusion of the ipsilateral superficial femoral artery (SFA), a target lesion length of more than 30 mm, and at least one patent (ie, < 50% stenosed) tibioperoneal runoff vessel (7). Detailed clinical characteristics are summarized in **Table 1**.

ABI Measurement

The ABI was measured with the use of a handheld 8-MHz Doppler ultrasound (US) device (Hadeco Bidop ES-100V3; Hayashi Denki, Kawasaki, Japan) and sphygmomanometric cuff with a 12-cm-wide bladder. After the patient was in a supine position for 5 minutes, the systolic pressures of all four limbs were measured in a quiet environment. Trained physicians recorded the brachial systolic pressures in the antecubital fossae of both arms, followed by the left and right posterior tibial arteries and dorsalis pedis (DP) arteries. Following a clockwise rotation, three separate measures of systolic pressure were obtained from each limb. In general, the ABI was calculated as the ratio of the higher of the two systolic pressures (from the posterior tibial and DP arteries) at the ankle to the average of the right and left brachial artery pressures; when there was a discrepancy

Table 1. Clinical Characteristics of Enrolled Patients

Characteristic	Value
Sex	
Male	9 (47.4)
Female	10 (52.6)
Rutherford classification	
Category 2	3 (15.8)
Category 3	5 (26.3)
Category 4	5 (26.3)
Category 5	4 (21.1)
Category 6	2 (10.5)
ABI distribution (%)	
0.70 < ABI < 0.9	10
0.3 < ABI < 0.7	65
ABI < 0.3	25
Hypertension	15 (78.9)
Diabetes mellitus	12 (63.2)
Coronary heart disease	5 (26.3)
Atrial fibrillation/other arrhythmias	4 (21.1)
Stroke	6 (31.6)
Renal failure	3 (15.8)
Smoking history	
Smoker	7 (36.8)
Nonsmoker	12 (63.2)

Note–Values in parentheses are percentages. Rutherford classification is as follows: category 2, moderate claudication; category 3, severe claudication; category 4, rest pain; category 5, ischemic ulceration not exceeding ulcer of the digits of the foot, minor tissue loss; category 6, severe ischemic ulcers or frank gangrene, major tissue loss.
ABI = ankle-brachial index.