Stability of Flow Velocity and Intracoronary Resistance in the Intracoronary Electrocardiogram-triggered Pressure Ratio

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Abstract

It has been found that the assessment of coronary artery lesions using the fractional flow reserve and instantaneous flow reserve measurements reduces the incidence of further cardiovascular events. Here, we investigated differences in the coronary flow velocity and resistance within the analysis interval between the instantaneous flow reserve (iFR) and the intracoronary electrocardiogram (IC-ECG)-triggered distal/aortic pressure (Pd/Pa) ratio (ICE-T). Thirty-three consecutive patients with stenoses that required coronary flow measurement were enrolled. ICE-T was defined as the average Pd/Pa ratio in the period corresponding to the isoelectric line of the IC-ECG. The index value, flow velocity, and intracoronary resistance during the analysis intervals of the iFR and ICE-T, both at rest and under hyperemia, were compared.

The index value and intracoronary resistance of the ICE-T were found to be significantly lower, while the flow velocity was significantly higher, than those of the iFR ($P < 0.001$), and all fluctuations in ICE-T values were also significantly smaller than those in the iFR.In conclusion, the ICE-T is theoretically superior to pressure-dependent indices for analyzing phases with low and stable resistance, without an increase in invasiveness.

Introduction

Several clinical trials have demonstrated that physiological assessment of coronary artery lesions using the measurement of the fractional flow reserve (FFR) and instantaneous flow reserve (iFR) in coronary interventions contributes to a decrease in cardiovascular events [1–6]. This physiological assessment is necessary to determine the indications for coronary interventions.

The iFR value is calculated as the coronary artery distal pressure (Pd) per aortic pressure (Pa) (Pd/Pa) in the absence of hyperemia, during the mid- to end-diastolic or wave-free period (WFP), in which the microvascular resistance is recognized as being low and stable [7, 8]. The current iFR algorithm (Volcano Corporation, Rancho Cordova, CA, USA; FFR software 2.5) uses an ECG-independent algorithm to identify the diastolic period using the pressure signal only [9]. However, the iFR values did not significantly differ from the index values analyzed for any diastolic time phase [10]. We have previously reported that prolongation of the corrected QTU (QTUc) during papaverine-induced hyperemia markedly lowered the iFR values [11]. These results suggested that the definition of the WFP based on aortic pressure should be discarded. Westerhof et al. argued that the assumption underlying the iFR violates physical principles; however, the iFR and FFR appear to be associated, indicating the practical utility of the iFR measure [12].

Intracoronary electrocardiogram (IC-ECG) findings are sensitive and selective in detecting regional myocardial potentials [13–18]. Although the sample size in our study was small, we have found that, in the period in which the resting Pd/Pa was low, the accuracy of the IC-ECG-triggered resting index (ICE-T) was superior to the iFR in diagnosing myocardial ischemia [19].

The pressure gradient is calculated according to Bernoulli's principle. This requires that the flow velocity must be fast and stable. Furthermore, as is evident in the iFR concept, it is crucial to select a phase with low and stable resistance and an absence of hyperemia to conform with Ohm's law. We hypothesized that the interval in which the IC-ECG potential is low and stable might be used as the low-resistance period in the coronary artery circulation. However, previous studies have not determined whether the intracoronary resistance does indeed decrease during the analysis interval of ICE-T. This study aimed to investigate the differences between the iFR and the ICE-T in blood flow velocity and resistance within the analysis interval.

Methods

Subject selection

This investigation was a prospective single-center study. Twenty-three consecutive patients who had undergone scheduled coronary angiography and coronary flow reserve (CFR) measurement for physiological lesion assessments at Todachuo General Hospital between October 2018 and January 2020 were enrolled. All patients had at least one stenosis in a large epicardial artery that required physiological assessment to determine the intervention indications. The exclusion criteria were a history of coronary artery bypass surgery, extremely tortuous coronary arteries, acute coronary syndrome, occluded coronary arteries, left main disease, coronary ostial stenosis, congestive heart failure, or an absolute contraindication to the use of adenosine triphosphate (ATP). This study was approved by the Institutional Review Board of Todachuo General Hospital (reference number: 0362), and the study was performed in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants after a complete explanation of the protocol and potential risks.

Catheterization and measurement of the instantaneous wave-free ratio at rest and during hyperemia

The coronary flow measurements of coronary artery stenosis were performed in the standard manner. Briefly, a digital archive (ComboMap) with a 0.014-inch dual sensor–equipped guidewire (Combowire; Philips-Volcano, San Diego, CA, USA) was used for all physiological measurements. A bolus of intracoronary nitrates (200–300 μg) was administered to all patients before the introduction of the pressure wires. The pressure was calibrated to normal atmospheric pressure before insertion of the wires and was equalized at the tip of the catheter before advancement of the catheter into the distal stenotic lesion.

The Doppler sensor's position was manipulated until an optimal and stable blood velocity signal was obtained distal to the lesion. ATP was then intravenously administered at a rate of 140 μg/kg/min for 3 minutes until steady-state hyperemia was achieved. Aortic pressure (Pa), coronary pressure (Pd), and flow velocity (V) were continuously recorded at rest and throughout the induction of maximum hyperemia. The

IC-ECG was recorded during the physiological measurements by connecting the proximal tip of the Combo wire to the unipolar lead terminal of a multichannel electrocardiogram recorder (RMC-4000M Cardio Master with EP amplifier system [JB400G]; Nihon Koden, Tokyo, Japan, or AXIOM Sensis HEMO EP128; Siemens AG, Munich, Germany) using a sterile double-alligator connector. These systems allow simultaneous multichannel recordings of ECGs of limb and chest leads during the IC-ECG recordings. The IC-ECG data were stored digitally for offline analysis.

iFR and ICE-T analysis

The pressure data were directly extracted from the digital archive of the Combo map device console. Using the data from the time of pressure equalization, the time phases of the Pd and flow velocity data were synchronized based on the Pa waveform. To identify variations in the pressure parameters during WFP, the iFR was calculated using the pressure data from three heartbeats included within the automatic iFR calculation data. The iFR was calculated as the Pd/Pa ratio during the WFP (from 25% into diastole until 5 ms before the end of diastole)[8]. The start of diastole was defined at the nadir of the dicrotic notch on the Pa, and the end of diastole as 50 ms before the upstroke in Pa from the subsequent ventricular contraction.

The IC-ECG data were analyzed using the multichannel ECG recorder. ECGs were examined by scaling up the sampling speed by 100 mm/s and the ECG signal amplitude by 10 mm/mV. The following points were traced on the IC-ECG: the beginning of the P-wave, beginning of the QRS complex, end of the T-wave, end of the U-wave, beginning of the subsequent P-wave, and beginning of the subsequent QRS complex. The isoelectric line was considered as the T-P segment preceding the QRS (or QS) complex. If hallmarks of the points were not distinct, then the isoelectric line was determined based on the observation that the electrical potential is small and parallel to the baseline. The time from the Q point to the start and end of the isoelectric line was measured. The IC-ECGs were interpreted by two cardiologists, who arrived at consensus during disagreements.

The start points of the systolic phase in the pressure waveform and the Q point in the IC-ECG were regarded as the same point, and the time-phases were synchronized. The IC-ECG-triggered Pd/Pa ratio (ICE-T) was defined as the average of the Pd/Pa ratio in the period corresponding to the isoelectric line (Figure 1).

Data analysis

The baseline clinical characteristics of the patients, including the number and locations of stenotic lesions, were determined. The iFR and ICE-T values were analyzed offline using MS-Excel (Microsoft Corp., Redmond, WA, USA). The intracoronary resistance (R) was calculated as the Pd value divided by the flow velocity at the same point in time. All indices were determined in a fully automated manner for three consecutive heartbeats and were then averaged. The differences between the minimum and maximum flow velocities during the analysis interval of each index were defined as Δflow velocity (ΔV) (Figure 2). The ΔPd/Pa and ΔR were similarly defined. The mean Pd/Pa, mean V, mean R, ΔPd/Pa, ΔV, and ΔR values of the ICT-T were compared with the iFR at rest and during hyperemia. The periods used for the analysis of the ICT-T were also compared. These comparisons were also performed for the left anterior descending coronary artery (LAD) and non-LAD, respectively.

Statistical analysis

Numerical data were expressed as mean ± SD. Paired *t*-tests were used for comparisons of the pressure parameters, flow velocity, resistance, and analysis period between the iFR and ICE-T both at rest and during hyperemia. P-values < 0.05 were considered statistically significant. Statistical analyses were performed using SPSS (SPSS 19; IBM Corporation, Armonk, NY, USA).

Results

Patient characteristics

The clinical characteristics of the patients are shown in Table 1. Twenty-three patients agreed to participate in this study. CFR and IC-ECG recordings were measured at 33 lesions, with all measurements proving successful and interpretable. The physiological assessment was most often conducted at the LAD (51.5%). The patients' mean age was 68 ± 11 years, and 19 (82.6%) were men. Five patients (21.7 %) had a history of myocardial infarction.

Table 1
Clinical characteristics of patients

Number of patients	23
Male, %	19 (82.6%)
Age, years	68 ± 11
Body weight, kg	66 ± 13
Body height, cm	162 ± 7
Measured artery:	33
total	17 (51.5%)
LAD	8 (24.2%)
LCX	8 (24.2%)
RCA	17 (73.9%)
Medical history, %:	7 (30.4%)
Hypertension	19 (82.6%)
Diabetes mellitus	8 (34.8%)
Dyslipidemia	5 (21.7%)
Current smoking	
Prior myocardial infarction	

Abbreviations: LAD, left anterior descending artery; LCX, left circumflex artery; RCA, right coronary artery.

Comparison of index values, pressure parameters, flow velocity, resistance, and analysis period between the iFR and ICE-T

The index pressure parameters, resistance, flow velocity, and the analysis period are shown in Table 2 and Fig. 3. The mean index value and resistance of the ICE-T were significantly lower than those of the iFR, both at rest and during hyperemia. The flow velocity of the ICE-T was significantly higher than that of the iFR both at rest and during hyperemia. The ΔPd/Pa, ΔV, and ΔR of the ICE-T were significantly smaller than those of the iFR. The periods used for the analysis of ICE-T were significantly shorter than those used for the iFR.

Table 2
Index pressure parameters, resistance, flow velocity, and the period used for the analysis

n = 33		**Rest**			**ATP**		
		iFR	ICE-T	P-value	iFR	ICE-T	P-value
index value	mean	0.922 ± 0.089	0.914 ± 0.095	0.00003	0.848 ± 0.096	0.828 ± 0.107	< 0.00001
	max	0.895 ± 0.232	0.934 ± 0.094	0.352	0.830 ± 0.215	0.871 ± 0.123	0.406
	min	0.900 ± 0.095	0.903 ± 0.096	0.055	0.776 ± 0.175	0.780 ± 0.175	0.125
	Δ	0.141 ± 0.249	0.025 ± 0.016	0.013	0.237 ± 0.286	0.037 ± 0.024	0.0004
flow velocity, cm/s	mean	20.2 ± 9.7	24.1 ± 11.2	< 0.00001	40.1 ± 18.7	48.9 ± 22.6	< 0.00001
	max	30.2 ± 15.0	29.0 ± 12.7	0.199	57.0 ± 25.5	54.8 ± 24.6	0.078
	min	9.4 ± 6.8	20.1 ± 10.3	< 0.00001	23.2 ± 19.5	42.9 ± 22.8	< 0.00001
	Δ	22.6 ± 14.0	8.4 ± 6.0	< 0.00001	39.4 ± 17.7	10.9 ± 6.9	< 0.00001
intracoronary resistance	mean	5.5 ± 3.8	4.7 ± 3.8	< 0.00001	2.3 ± 2.3	1.8 ± 1.3	0.004
	max	14.0 ± 8.6	8.3 ± 7.4	0.00005	6.1 ± 5.0	3.3 ± 3.8	< 0.00001
	min	3.4 ± 2.6	3.4 ± 2.5	0.640	1.2 ± 0.7	1.3 ± 0.7	0.002
	Δ	8.0 ± 6.0	2.2 ± 4.6	< 0.00001	3.2 ± 3.6	0.9 ± 3.3	< 0.00001
analysis interval, msec		406 ± 83	140 ± 76	< 0.00001	394 ± 91	113 ± 50	< 0.00001
Values are given as means with standard deviations; differences were assessed using paired t-tests.							
Abbreviations: LAD, left anterior descending artery; LCX, left circumflex artery; RCA, right coronary artery.							

A comparison of the iFR and the ICE-T in terms of the artery used for measurement (LAD or non-LAD) and condition (rest or ATP-induced hyperemia) is shown in Table 3. The mean flow velocity of the LAD within the iFR analysis interval was higher than that of the non-LAD, and the mean resistance of the LAD was lower than that of the non-LAD, although these differences were not significant under either resting or hyperemic conditions (flow velocity: rest p = 0.101, hyperemia p = 0.060; resistance: rest p = 0.089, hyperemia p = 0.190). At rest, in both the LAD and non-LAD, the mean index value and mean resistance of the ICE-T were significantly lower than those of the iFR, while the mean flow velocity of the ICE-T was significantly higher than that of the iFR, and the analysis interval of the ICE-T was significantly shorter than that of the iFR. ΔPd/Pa, ΔV, and ΔR were significantly smaller in the ICE-T than in the iFR for both the LAD and non-LAD.

Under hyperemia, in both the LAD and non-LAD, the ICE-T value was significantly lower than the iFR value, the mean flow velocity of the ICE-T was significantly higher than that of the iFR, and the analysis interval of the ICE-T was significantly shorter. While the mean resistance of the ICE-T was lower than that of the iFR, this difference was only significant in the LAD (LAD: $P = 0.002$, non-LAD: $P = 0.065$). ΔPd/Pa, ΔV, and ΔR were significantly smaller in the ICE-T than in the iFR for both the LAD and non-LAD.

An example of the flow and resistance waveform and the IC-ECG recorded in the LAD under hyperemia induced by ATP is shown in Fig. 4. Although the isoelectric phase of the IC-ECG waveform was short, the isoelectric line of the IC-ECG was caught just after the peak flow velocity.

Table 3

A comparison of iFR and ICE-T by measurement artery (LAD or non-LAD) and condition (A: rest, B: hyperemia)

(A)

Rest		LAD (n=17)			non-LAD (n=16)		
		iFR	ICE-T	P-value	iFR	ICE-T	P-value
index value	mean	0.910 ±0.088	0.906 ±0.093	0.025	0.934 ±0.092	0.922 ±0.099	0.0003
	max	0.817 ±0.297	0.931 ±0.093	0.157	0.978 ±0.080	0.938 ±0.098	0.00004
	min	0.896 ±0.095	0.897 ±0.095	0.415	0.905 ±0.098	0.910 ±0.099	0.084
	Δ	0.204 ±0.337	0.022 ±0.014	0.043	0.073 ±0.036	0.028 ±0.018	0.00001
flow velocity, cm/s	mean	22.9 ±10.4	27.0 ±12.0	0.0005	17.3 ±8.2	21.1 ±9.7	0.00001
	max	33.4 ±16.3	31.8 ±13.1	0.267	26.8 ±13.1	26.1 ±11.9	0.538
	min	11.8 ±8.3	23.1 ±11.2	0.002	6.7 ±3.2	16.9 ±8.5	0.00004
	Δ	25.0 ±15.3	7.6 ±4.4	0.0001	20.1 ±12.3	9.2 ±7.4	0.00034
intracoronary resistance	mean	4.4 ±1.9	3.6 ±1.5	0.0003	6.6 ±4.8	5.9 ±5.1	0.001
	max	14.0 ±9.5	8.5 ±6.8	0.011	14.0 ±7.8	8.1 ±8.2	0.001
	min	2.6 ±1.5	2.6 ±1.4	0.974	4.2 ±3.2	4.2 ±3.1	0.518
	Δ	6.0 ±4.1	1.1 ±1.4	0.0003	10.2 ±7.0	3.2 ±6.3	0.00006
analysis interval, msec		390 ±79	123 ±79	<0.00001	424 ±86	157 ±70	<0.00001

Table 3

(B)

ATP		LAD (n=17)			non-LAD (n=16)		
		iFR	ICE-T	P-value	iFR	ICE-T	P-value
index value	mean	0.850 ±0.086	0.838 ±0.093	0.0009	0.845 ±0.109	0.817 ±0.122	0.00003
	max	0.743 ±0.264	0.896 ±0.128	0.101	0.922 ±0.085	0.845 ±0.116	<0.00001
	min	0.761 ±0.216	0.766 ±0.215	0.276	0.792 ±0.124	0.795 ±0.124	0.228
	Δ	0.339 ±0.371	0.025 ±0.016	0.003	0.130 ±0.056	0.050 ±0.024	<0.00001
flow velocity, cm/s	mean	46.0 ±19.9	55.6 ±23.8	0.0003	33.8 ±15.5	41.8 ±19.5	0.00001
	max	65.4 ±27.6	62.0 ±26.8	0.15886	48.1 ±20.3	47.1 ±19.9	0.133
	min	29.8 ±23.7	49.5 ±24.5	0.0001	16.1 ±10.7	35.9 ±19.3	<0.00001
	Δ	46.4 ±19.6	10.6 ±8.6	<0.00001	32.0 ±11.9	11.2 ±4.7	<0.00001
intracoronary resistance	mean	1.8 ±0.9	1.4 ±0.6	0.0021	2.9 ±3.1	2.1 ±1.7	0.065
	max	5.7 ±4.0	3.1 ±2.4	0.004	6.6 ±5.9	3.6 ±5.0	0.0002
	min	1.0 ±0.5	1.1 ±0.5	0.080	1.4 ±0.7	1.4 ±0.7	0.012
	Δ	2.2 ±1.6	0.2 ±0.2	0.00004	4.3 ±4.8	1.7 ±4.6	0.00002
analysis interval, msec		419 ±110	110 ±61	<0.00001	368 ±59	116 ±38	<0.00001

Values are given as means with standard deviations; differences were assessed using paired t-tests.

Abbreviations: LAD, left anterior descending artery; non-LAD, left circumflex artery and right coronary artery; iFR, instantaneous flow reserve; ICE-T, intracoronary electrocardiogram-triggered resting index

Discussion

This study showed that determination of the analysis interval using the isoelectric line of the IC-ECG resulted in significantly lower index values, higher flow, and lower resistance than for the iFR, and also demonstrated that within each analysis interval, all the fluctuations (ΔPd/Pa, ΔV, and ΔR) of the ICE-T were significantly smaller than those of the iFR. The results were the same for the LAD and non-LAD with different blood flow patterns, at rest and during hyperemia. Our study strongly suggests that the ICE-T, which relies on IC-ECG, is an ideal method for ischemia diagnosis in terms of Ohm’s law and Bernoulli's principle, compared to a pressure-dependent index.

The iFR value is calculated as the Pd/Pa ratio during the mid- to end-diastolic period known as the WFP, during which the microvascular resistance is presumed to be low and stable [7,8]. The diastasis during the diastolic phase is characterized by considerably reduced left ventricular (LV) myocardial activity and meets the concept of the WFP. However, both the heart rate and myocardial condition affect the diastasis period to preserve the LV stroke volume [20]. Therefore, even in the same coronary artery of the same patient, the interval of low intracoronary resistance can easily vary. Furthermore, we have previously reported that the prolongation of the QTUc during papaverine-induced hyperemia markedly lowered the iFR values [11]. However, the WFP is defined as representing approximately 75% of mid to late diastole, excluding the initial 25% and the final 5 msec, and neither myocardial activation nor the repolarization time changes the proportion of the WFP in diastole [8,21. The heart rate was an important factor accounting for the discrepancy between the ischemic diagnosis of FFR and the iFR because the heart rate only affected the iFR value and not the FFR value [22,23]. Therefore, distinguishing the low intracoronary resistance phase from the aortic pressure might be difficult.

Coronary blood flow predominates in the diastole period [24]. Myocardial contraction compresses the intramyocardial coronary artery, increasing resistance, and reducing blood flow during the systolic period. Most of the blood flow in the LAD occurs during diastole. However, the right coronary artery (RCA) has a flow-velocity pattern that is less diastolic-dominant than that of the LAD and has different proximal and distal flow-velocity patterns [25-27]. Coronary artery stenosis mainly reduces diastolic blood pressure and coronary blood flow; hence, the diastolic/systolic velocity ratio changes before and after the percutaneous coronary intervention [25. Although many factors are affecting the blood flow pattern, the iFR is completely dependent on the aortic pressure waveform to determine the analysis interval, the WFP[9].

The index value of the ICE-T was lower, the flow velocity was higher, and the intracoronary resistance was lower than those of the iFR in all conditions where different coronary arteries were measured and with or without hyperemia. The usefulness of IC-ECG in predicting the microvascular obstruction of myocardial infarction [28] and post-procedural myocardial injury in angina pectoris has also been reported [29]. These reports indicate that the local myocardial condition can be assessed sensitively using the IC-ECG. IC-ECG requires a shorter analysis period than iFR because it can selectively detect finer electrical potentials representing cardiac muscle activity near the tip of the pressure wire where the pressure sensor is located [30]. Therefore, the ICE-T measure might select an analysis interval with lower intracoronary resistance than the aortic pressure-dependent iFR measure regardless of the measurement conditions.

The ICE-T value under hyperemia was clinically significantly lower than the iFR value (ICE-T 0.848 ± 0.096, iFR 0.828 ± 0.107, $p < 0.0001$). Although the sample sizes in both studies were small, diastolic-FFR (d-FFR) was useful for ischemia diagnosis and determination of blood flow compared with whole-cardiac cycle-FFR [31,32]. However, d-FFR is not widely used due to the complexity of its measurement. This study showed that the measurement of ICE-T was simple, accurate, and non-invasive. We speculate that the determination of the d-FFR in the LAD artery may contribute to an appropriate diagnosis of myocardial ischemia because the greater part of coronary blood flow occurs during the diastolic phase of the cardiac cycle. Although further studies of clinical significance are needed, the hyperemic ICE-T may represent a novel d-FFR index. The widespread use of the ICE-T requires the development of an automated analysis system for IC-ECG.

This study has some limitations. First, the study was conducted on a relatively small number of patients. Second, it is possible that the pressure wire might capture the electrical potential proximal to the stenosis. Nevertheless, we recently reported that the IC-ECG was captured near the tip of the pressure wire [30]. Moreover, this system selectively used the low myocardial electrical activity phase. Therefore, although the analysis interval is short due to the potential noise from the proximal coronary arteries, its influence on the index value will be small. Nevertheless, the ICE-T is a promising index for the accurate diagnosis of myocardial ischemia due to coronary artery stenosis. Further multi-center studies are needed to confirm the clinical significance of the ICE-T.In conclusion, the index based on the isoelectric line of the IC-ECG showed significantly and clinically lower index values, higher flow, and lower resistance than those of the iFR, and all these fluctuations of the ICE-T were significantly smaller than those of the iFR at rest and during hyperemia. The ICE-T measurement is consistent with the iFR concept of selecting the phase of low and stable resistance and is a better index in terms of Bernoulli's principle and Ohm’s law, in contrast to using the pressure-dependent index. However, further studies are needed to confirm the clinical significance of the new index ICE-T at rest and under hyperemia.

Declarations

Authors’ contributions

MN and TU designed the study and wrote the initial draft of the manuscript. NT contributed to data analysis and interpretation and wrote the manuscript. All other authors critically reviewed the manuscript.

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None.

Disclosures

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Human Subjects/Informed Consent Statement

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000. Informed consent was obtained from all patients included in the study.

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Figures

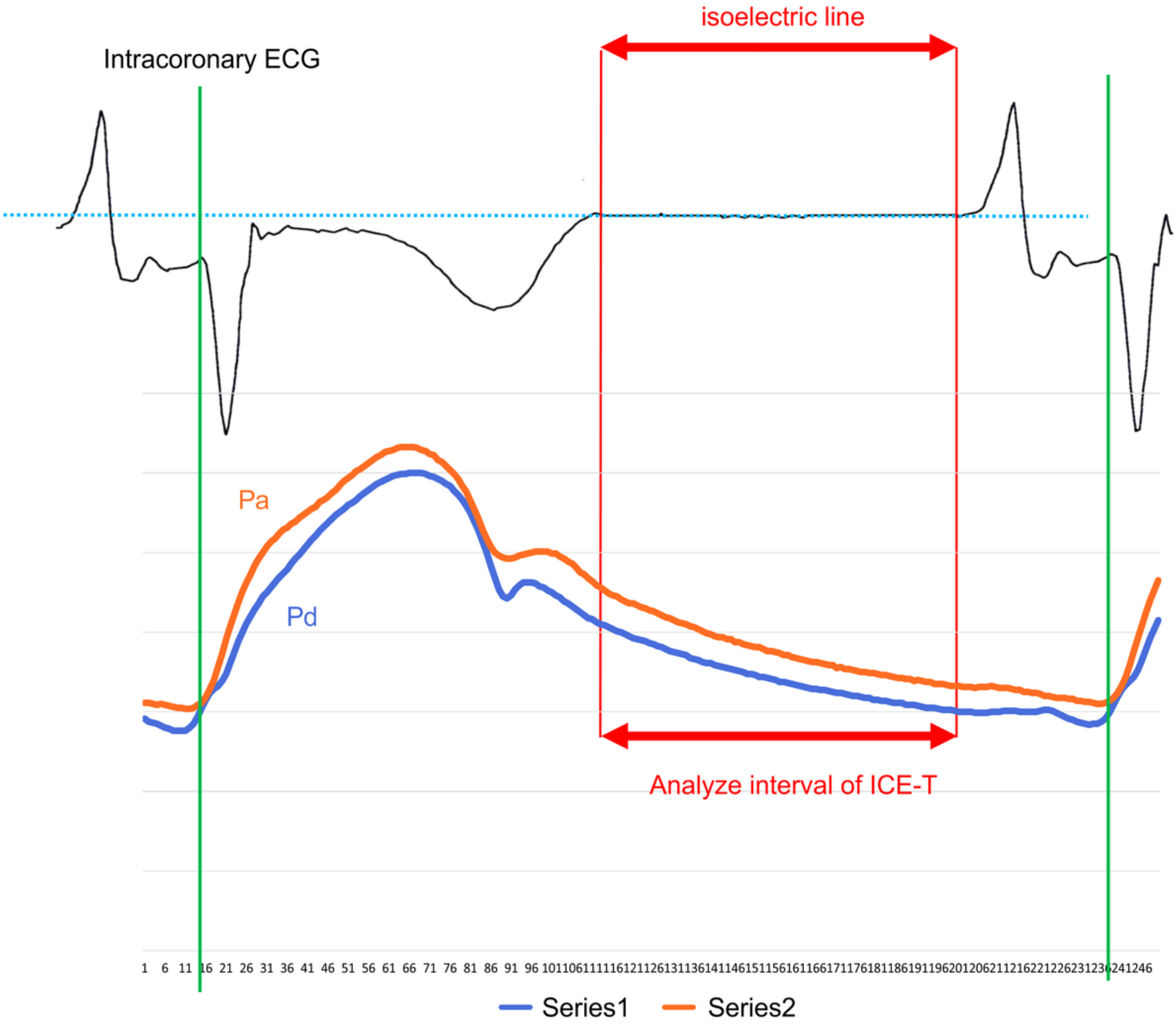

Figure 1

Calculation method for the intracoronary electrocardiogram-based pressure index First, the Q point of the intracoronary electrocardiogram (IC-ECG) was synchronized with the start points of the systolic phase in the pressure waveform. The IC-ECG-triggered distal/aortic pressure (Pd/Pa) ratio was defined as the average of Pd/Pa in the period corresponding to the isoelectric line.

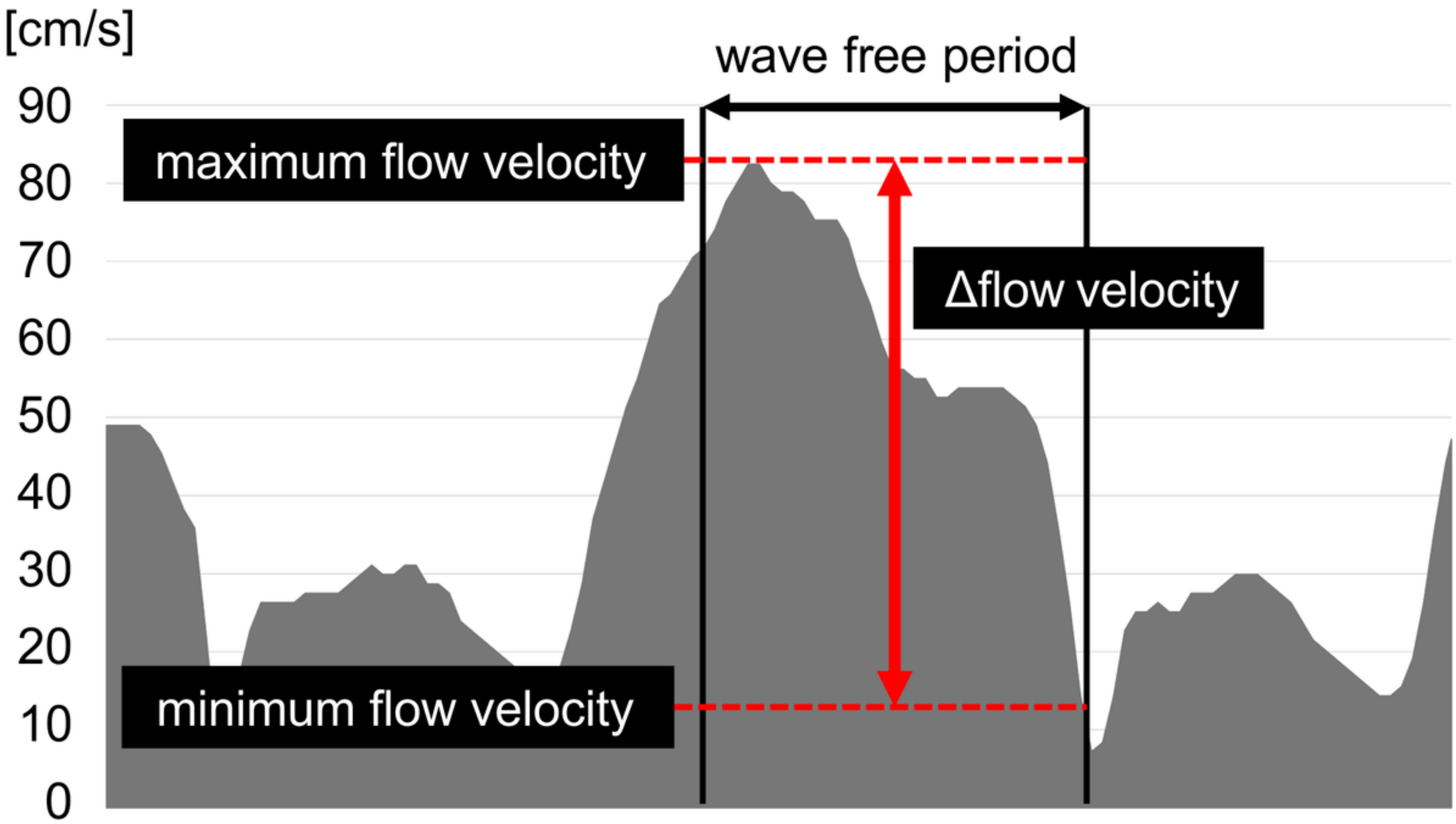

Figure 2

Definition of Δflow velocity Differences between the minimum and the maximum flow velocity during the analysis interval of each index were defined as Δflow velocity. ΔPd/Pa and ΔResistance were similarly defined. Pd/Pa: distal/aortic pressure

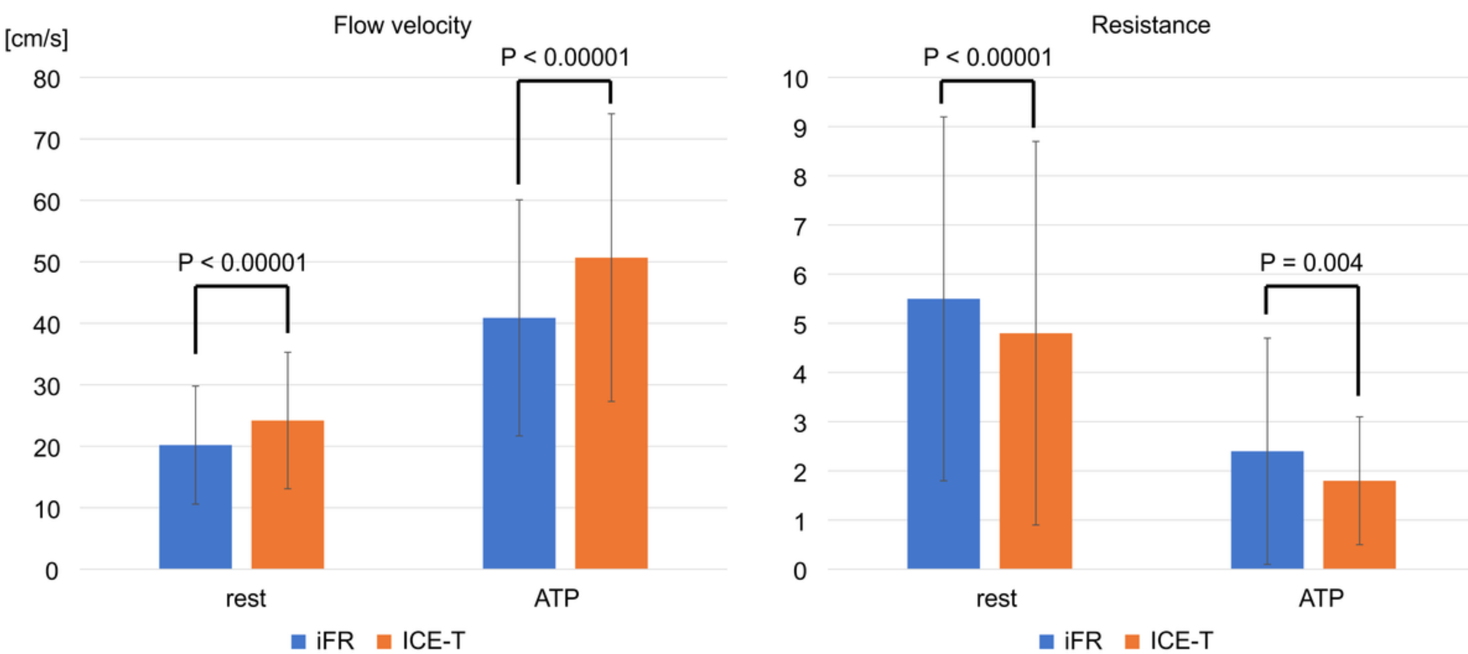

Figure 3

Comparison of flow velocity and resistance between the iFR and the ICE-T The mean resistance of the ICE-T was significantly lower than that of iFR both at rest and during hyperemia. The mean flow velocity of the ICE-T was significantly higher than that of the iFR both at rest and during hyperemia. iFR: instantaneous flow reserve; ICE-T: intracoronary electrocardiogram-triggered distal/aortic pressure ratio

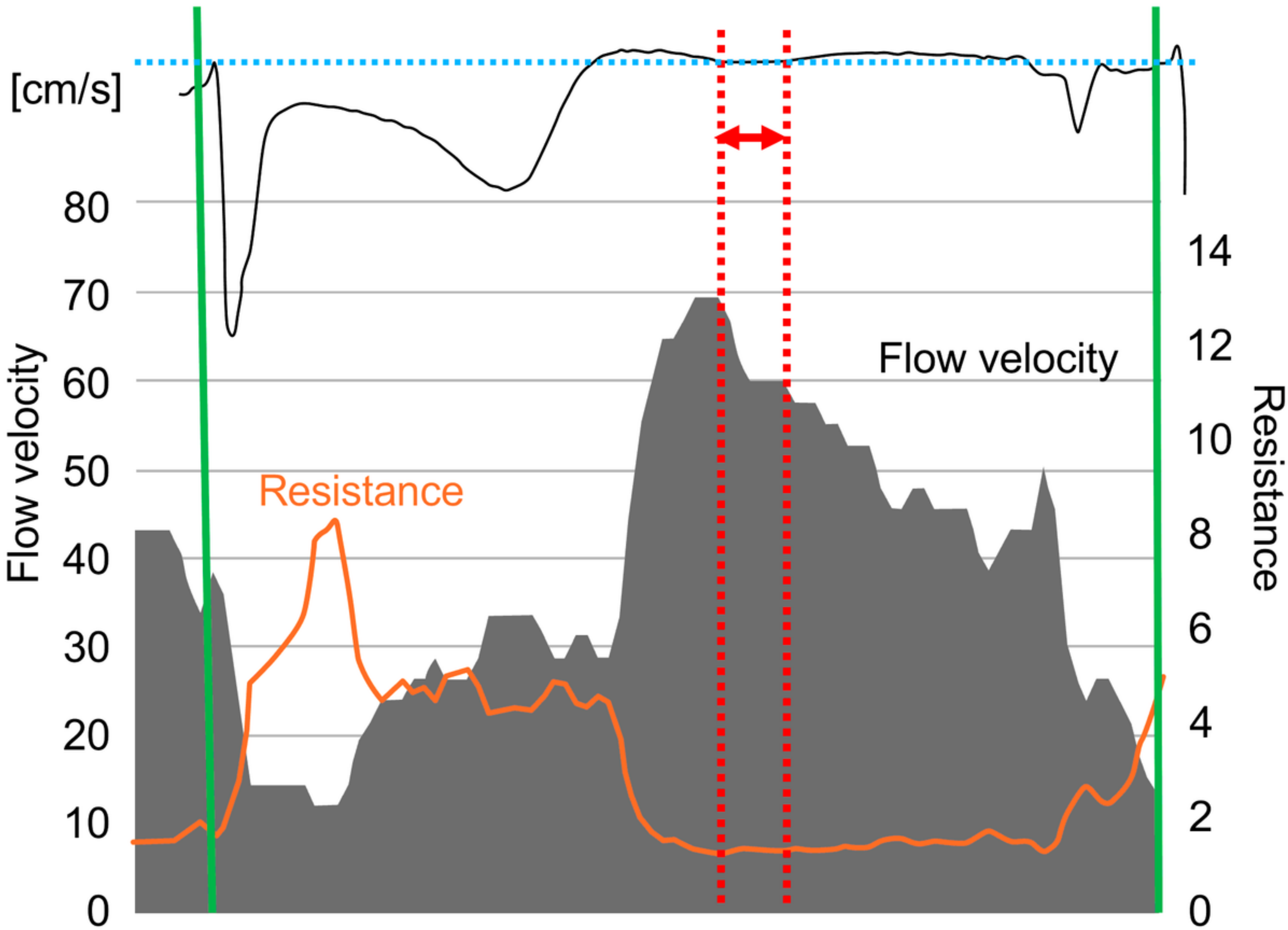

Figure 4

An example of flow velocity, resistance, and IC-ECG recorded in the left anterior descending coronary artery under hyperemia The flow velocity decreased sharply after reaching a high peak flow. The isoelectric line of the IC-ECG detected the phase immediately after the peak flow velocity. IC-ECG: intracoronary electrocardiogram