Pulsatility of Ascending Aortic Pressure Waveform Is a Powerful Predictor of Restenosis After Percutaneous Transluminal Coronary Angioplasty

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Background—Because ascending aortic pressure has a greater effect on coronary perfusion during diastole than systole, we hypothesized that a high coronary diastolic-to-systolic pressure ratio prevents coronary lesions from restenosing after percutaneous transluminal coronary angioplasty (PTCA) and that ascending aortic pulsatility relative to mean pressure is higher in patients with restenosis than in those without restenosis. The purpose of this study was to evaluate prospectively whether the morphology of the ascending aortic pressure wave can be used to predict restenosis after PTCA.

Methods and Results—We measured the coronary artery diameter and the aortic pressure before PTCA. To quantify the relative magnitude of the pulsatile-to-mean aortic pressure, we normalized the pulse pressure to mean pressure and referred to this value as the fractional pulse pressure (PPf). We prospectively investigated the effect of PPf in relation to subsequent risk of restenosis after PTCA in patients with coronary artery disease. PPf was a powerful predictor of restenosis. Crude cumulative incidence rates of restenosis were 17.6% for the lowest, 33.3% for the middle, and 77.8% for the highest tertile of PPf levels. After adjustments for age, smoking habits, systolic blood pressure, type 2 diabetes, hypercholesterolemia, old myocardial infarction, vessel location, vessel size, and sex, the odds ratio of restenosis was 33.5 (95% confidence interval, 2.04 to 550.6) for the highest tertile of the PPf level compared with the lowest tertile level.

Conclusions—Pulsatility of the ascending aortic pressure is a predictive factor for restenosis after PTCA. (Circulation. 2000;101:470-472.)

Key Words: mechanics ■ blood pressure ■ restenosis

The arterial pressure waveform is the result of an interaction between the heart and the arterial system. Therefore, the magnitude and shape of the pressure pulse are affected by changes in aortic input impedance or alterations in cardiac function.1 When characteristic impedance increases or systemic arteries stiffen under conditions of fixed cardiac function and peripheral resistance, the pulse pressure increases and diastolic aortic pressure decreases. Because coronary perfusion primarily occurs during diastole rather than systole, adequate coronary perfusion is most important during diastole.2 In the ascending aorta with increasing characteristic impedance and/or a stiffening arterial wall, the perfusion pressure and coronary flow during diastole decrease. In contrast, in a compliant ascending aorta, the perfusion pressure and coronary perfusion during diastole increase.

The use of an intra-aortic balloon pump may decrease restenosis after percutaneous transluminal coronary angioplasty (PTCA).3 The diastolic augmentation induced by the pump increases coronary perfusion flow and pressure and prevents narrowed coronary arteries from restenosing after PTCA. This finding suggests that the aorta with increasing characteristic impedance and/or a stiffening arterial wall may decrease coronary perfusion and increase the rate of restenosis, whereas a more compliant aorta increases coronary perfusion and decreases the rate of restenosis after PTCA.

On the basis of these vascular mechanics, we hypothesized that ascending aortic pulsatility would predict the occurrence of restenosis after PTCA in patients with similar cardiac function. Our results showed that although conventional measurements made using coronary angiography failed to predict the risk of restenosis, ascending aortic pulsatility was useful in predicting restenosis after PTCA.

Methods

Study Subjects
We studied 53 consecutive patients, 47 to 74 years of age, who were admitted to the Ishikiriseiki Hospital between January 1993 and December 1998 for revascularization of coronary artery disease and who were subsequently diagnosed as having stable angina pectoris or silent myocardial ischemia. The enrollment criteria for the study included successful coronary balloon angioplasty, aortic pressure...
measurements made before angioplasty, and coronary angiography performed 3 months after angioplasty. To standardize (approximately) cardiac function, patients were enrolled in this study only if their ejection fraction by left ventriculography exceeded 50%. We excluded 39 patients because their ejection fractions were poor (<50%), 47 patients with acute coronary syndromes, and 21 patients with chronic renal failure. The protocol was performed in accordance with our Institutional Guidelines for Human Research, and each patient provided a written statement of informed consent for the diagnostic and therapeutic procedures performed that stated the results could be used for prospective studies.

Measurement of Hemodynamic Variables

Hemodynamic measurements were made with the patient in the supine position before PTCA. Aortic pressure was measured using a fluid-filled system (5F pig-tail catheter) at the ascending aorta. A hard copy was made of the pressure tracing using a chart recorder (Nihon Koden, Surgical Monitoring System) at a paper speed of 100 mm/s. We compared tracings of systolic, diastolic, mean, and pulse pressures in patients with and without restenosis. Pulsatility was characterized as the ratio of pulse pressure to mean pressure, ie, as the fractional pulse pressure of the artery (PPf).

Measurement of Angiographic Variables

Cardiac catheterization and PTCA were performed using a standard technique.4 Only conventional balloon angioplasty was allowed in this study. Coronary angiography was performed before and after PTCA and at follow-up 3 months later. Optimal views of the target lesions from all technically suitable angiograms were analyzed using the median package.

Statistical Analysis

Values were expressed as mean±SD. Categoric variables were compared using the χ² test. Differences in the mean values between the 2 groups were compared using an unpaired t test. P<0.05 was considered statistically significant. Multiple logistic regression analysis was used to evaluate the simultaneous effects of PPf, age, smoking habits (current smokers or nonsmokers), systolic blood pressure, type 2 diabetes (yes or no), hypercholesterolemia (yes or no), old myocardial infarction (yes or no), vessel location, final MLD, and sex. The linear trends in risks were evaluated by entering indicators for each categorical level of exposure using the median value for each category. We calculated the 95% confidence interval (CI) for each odds ratio (OR), and all P values were 2-tailed. Statistical analyses were performed using the SPSS 8.0 software package.

Results

Baseline Clinical and Angiographic Characteristics

The baseline clinical characteristics of the study group are summarized in Table 1. Although the distribution of sex and target lesion; the presence of hypertension, diabetes mellitus, previous myocardial infarction, or hypercholesterolemia; and smoking status were similar in the 2 groups, the mean age was higher in patients with restenosis than in those without restenosis. No significant differences existed between patients with and without restenosis in reference lumen diameters, MLDs, mean stenosis severity before PTCA, and final MLDs. No significant differences existed in heart rate and ejection fraction between the 2 groups. Although aortic systolic, diastolic, and mean pressures were not different, the pulse pressure was slightly higher in patients with restenosis than in those without restenosis (76±15 and 64±20 mm Hg, respectively; P=0.02), and PPf was significantly higher in patients with restenosis than in those without restenosis (0.76±0.17 and 0.62±0.16, respectively; P=0.003). The relationship between PPf and late loss index could be expressed with the following equation (R=0.46, P<0.01): PPf=[0.14×(late loss index)]+0.63.

Multivariate Analysis of the Risk for Restenosis

To examine whether PPf was associated with the risk of restenosis after PTCA in this study population, all patients were classified into tertiles of PPf level. PPf was significantly and positively associated with restenosis after PTCA (Table 2). Crude cumulative incidence rates of restenosis were 17.6% for the lowest, 33.3% for the middle, and 77.8% for the highest tertile of PPf levels (P<0.001 for trend). The crude OR of restenosis was 2.33 (95% CI, 0.48 to 11.4) among the population of tertile 2 and 16.33 (95% CI, 3.07 to 86.8) among those of tertile 3 compared with those of tertile 1. After adjustment for age, sex, smoking status, systolic blood pressure, vessel location, final MLD, hypercholesterolemia, diabetes mellitus, and previous myocardial infarction, PPf was strongly associated with an increased risk of reste-
nondetected pulse pressure to be high relative to the mean pressure. In contrast, diastolic pressure relative to mean pressure is reduced because stiffened arteries shorten the time constant of diastolic pressure decay. Thus, a large pulse pressure relative to mean pressure is the characteristic waveform of stiffened arteries. Some investigators have attributed this widened pulse pressure to increased characteristic impedance in systemic arteries.7

To further quantify the effect of PPF on restenosis after PTCA, we modeled PPF as a continuous variable. The results suggested that the multiple-adjusted OR of restenosis after PTCA was increased by 88% when PPF was increased by 0.1 (OR, 1.88; 95% CI, 1.01 to 3.64).

**Discussion**

We showed that the ascending aortic pressure waveform analysis focusing on pulsatility may predict restenosis after PTCA.

**Mechanism of Pulsatility in the Ascending Aorta**

The proximal aortic waveform reflects the aortic input impedance. Arteriosclerosis results in a decrease in compliance of the aortic artery and an increase in characteristic impedance under conditions of similar cardiac function and peripheral resistance. Although characteristic impedance reflects the dynamic mechanical properties of the arteries, it behaves as if it were a viscous resistance.6 This causes the systolic pressure to be high relative to the mean pressure. In contrast, diastolic pressure relative to mean pressure is reduced because stiffened arteries shorten the time constant of diastolic pressure decay. Thus, a large pulse pressure relative to mean pressure is the characteristic waveform of stiffened arteries. Some investigators have attributed this widened pulse pressure to decreased arterial compliance and increased characteristic impedance in systemic arteries.7

**Clinical Implications of Predicting Restenosis on the Basis of Morphology of the Aortic Pressure Waveform**

Although unfavorable lipid profile, elevated plasma fibrinogen, and diabetes mellitus were identified as predictors of restenosis after balloon PTCA,8 the effects of aortic pressure waveform on the occurrence of restenosis have not been previously reported. Because the measurement of aortic artery pressure by a flow-directed catheter is a routine procedure on diagnostic coronary angiography, the use of morphological analysis of the aortic pressure waveform for detecting patients at an increased risk for restenosis is an extremely attractive clinical tool.

**Limitations**

We analyzed a limited number of patients. Therefore, other variables commonly associated with restenosis were not useful for predicting restenosis in this study. To generalize the results of this study, a multivariate analysis should be performed in a large number of patients. Nevertheless, we expect that the accentuated pulsatility relative to mean pressure observed in patients with restenosis will remain a useful and valid observation because it is based on a fundamental mechanical characteristic of aortic arterial pressure.

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**References**


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