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Editor's comment: as subscribers to the on-line version of the journal may know, articles published in the January issue each year are made available without charge. With this issue, the Publisher is pleased to introduce a new feature whereby one article per issue is selected by an Editor to be made available on the same basis. The article below reports work to develop cardiac catheterisation technology that enables the dynamics of coronary pressure and flow to be recorded simultaneously, and has been selected for its potential contribution to the field of interventional cardiology.

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A combination of thermal methods to assess coronary pressure and flow dynamics with a pressure-sensing guide wire
[Universally Available]

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ABSTRACT

Measurement of coronary pressure and absolute flow dynamics have shown great potential in discerning different types of coronary circulatory disease. In the present study, the feasibility of assessing pressure and flow dynamics with a combination of two thermal methods, developed in combination with a pressure-sensor-tipped guide wire, was evaluated in an *in vitro* coronary model. A continuous infusion thermodilution method was employed to determine the average flow, whereas a thermal anemometric method was utilized to assess the pressure and flow dynamics, simultaneously. In the latter method, the electrical power supplied to an element, kept at constant temperature above ambient temperature, was used as a measure for the shear rate.

It was found that, using a single calibration function, the method was able to assess coronary pressure and flow dynamics for different flow amplitudes, heart rates, and different pressure wires. However, due to the fact that the thermal anemometric method cannot detect local shear rate reversal, the method was unable to reliably measure flow dynamics close to zero. Nevertheless, the combined methodology was able to reliably assess diastolic hemodynamics. The diastolic peak flow and average diastolic resistance could be determined with a small relative error of $(8 \pm 7)\%$ and $(7 \pm 5)\%$, respectively.

1. Introduction

Due to the recent developments in guide wire mounted sensors, the dynamics of coronary pressure and flow has become of interest to elucidate the complex interaction between the coronary circulation and the myocardium [1,2]. Analysis of coronary hemodynamics has shown great potential in discerning different types of arterial [3], microvascular [4–6], and cardiac [7] disease based on abnormal hemodynamics. The current diagnostic approaches used are based on pressure and/or flow in a specific part of the cardiac cycle, *e.g. via* wave intensity analysis [8,9]. Ideally, pressure and flow should be measured simultaneously with a single guide wire. In clinical practice, a sensor-tipped guide wire (ComboWireXT, Volcano, San Diego, CA) is available that combines pressure and flow velocity assessment [10], measured with a Doppler-crystal. Adequate Doppler-derived velocity signals can, however, be difficult to obtain, resulting in a poor Doppler signal in 10–19% of all patients [11,12]. Additionally, the blood velocity is measured instead of flow, which means that the obtained signal depends on both the size of the vessel and radial position of the guide wire.

The aim of present work is to develop a method able to simultaneously assess the dynamics of coronary pressure and volumetric flow. The proposed methodology consists of a combination of a thermal anemometric and a thermodilution based method with a

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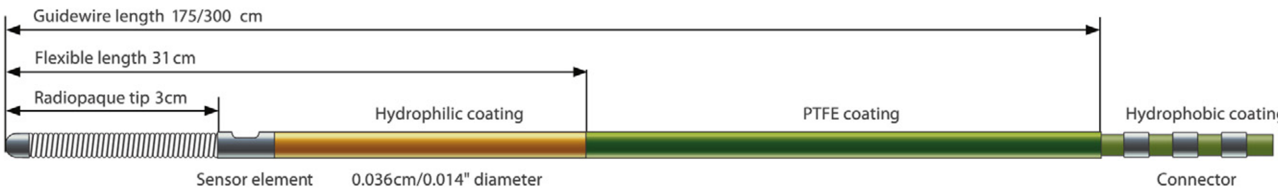

Fig. 1. Schematic representation of the PressureWire Certus.
Adapted from St. Jude Medical (http://www.sjmprofessional.com).

pressure and temperature sensor-tipped guide wire (PressureWire Certus, St. Jude Medical, St. Paul, MN), originally designed to measure coronary pressure for the determination of fractional flow reserve (FFR), see *e.g.* Tonino et al. [13].

In previous research it was shown that the PressureWire could be adapted to be operated as a thermal anemometer [14]. By measuring the power required to keep an element on the tip of the PressureWire at constant temperature, coronary flow reserve (CFR) could be determined accurately. Additionally, a clear relation between the dynamics of the applied flow and the measured electrical power was found, which was the motivation of this study. Similar to measurements with the guide wire-mounted Doppler-crystal, this method could not directly assess the dynamics of volumetric flow, since the sensor response was only determined by the shear rate at the sensor surface.

Another method to assess flow, developed in combination with the PressureWire, utilized the principle of thermodilution and was investigated by van't Veer et al. [15] and successfully applied in the clinic by Aarnoudse et al. [16]. Absolute volumetric flow rate could be measured, by continuously infusing a saline solution at room temperature and measuring the temperatures of the blood, infusate, and the mixture distal to the infusion site. With this method, however, only the mean flow could be measured.

In this study, a methodology is developed in which the continuous thermodilution method is used to calibrate the dynamic signals obtained with the thermal anemometric method for assessing the dynamics of volumetric flow. In addition, the thermal anemometric method is improved, to enable simultaneous assessment of flow and pressure, instead of sequential measurements. In *in vitro* experiments with a physiologically representative model of the coronary circulation [17] the methods are evaluated under well-controlled conditions. The method is tested with different PressureWires, vessels diameters, heart rate, and flow amplitudes. To demonstrate the clinical relevance of the combined methodology, the diastolic peak flow and average diastolic resistance obtained with the method are compared to the values obtained with reference flow and pressure measurements.

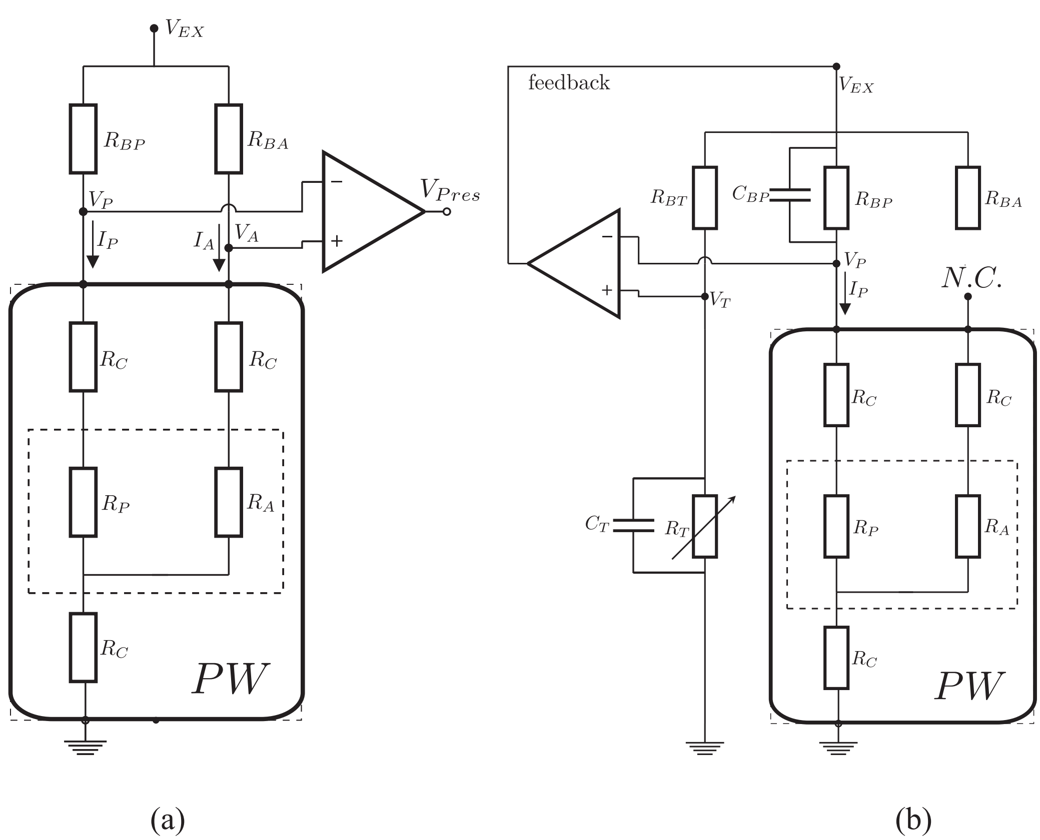

Fig. 2. (a) Schematic representation of the electrical circuit to measure pressure with the PressureWire (PW). The difference V_A-V_P is a measure for the pressure. (b) The feedback controlled Wheatstone bridge to heat R_P to a constant temperature above ambient temperature. R_T is a potentiometer, used to set the temperature of R_P, and capacitors C_{BP} and C_{BA} are incorporated to stabilize the bridge. The branch with the pressure sensitive resistor R_A is not connected (N.C.). The electrical power to the passive branch ($R_P + 2R_C$) is a measure for the heat transferred to the flow and therefore a measure for the local flow rate.