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Pre-Clinical

In vitro assessment of physiological impact of recipient artery intervention on the contralateral donor artery

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ABSTRACT

Background: Donor artery fractional flow reserve (FFR) often improves after treatment of recipient artery stenosis, but the physiological mechanism underlying this phenomenon has not been elucidated. This study aimed to assess two novel equations that explain the donor–recipient artery interaction.
Method: Eq. (A) predicts the donor artery FFR after complete release of recipient artery stenosis, while Eq. (B) predicts the donor artery FFR after partial release of recipient artery stenosis. Eq. (B) is a general form of Eq. (A).

$$FFR'_{1-pred} = ((FFR_1-CFI_1)(FFR_2-CFI_2)-CFI_1CFI_2(1-FFR_1)(1-FFR_2)+CFI_1(1-FFR_1)\ (1-CFI_2))/((1-CFI_1)(FFR_2-CFI_2)) \tag{A}$$

$$FFR''_{1-pred} = ((FFR_1-CFI_1)\ (FFR_2-CFI_2)-CFI_1CFI_2(1-FFR_1)(1-FFR_2)+CFI_1(1-FFR_1)(1-CFI_2)FFR'_2)/((1-CFI_1)(FFR_2-CFI_2)) \tag{B}$$

Eqs. (A) and (B) were assessed using an in vitro model of coronary circulation with a collateral channel connecting the donor and recipient arteries.
Results: The donor artery FFR always improved after releasing the recipient artery stenosis. A good linear correlation was found between the predicted FFR of Eq. (A) and the actual FFR (n = 40, r = 0.95, p < 0.0001) and between the predicted FFR of Eq. (B) and the actual FFR (n = 40, r = 0.94, p < 0.0001).
Conclusions: Eqs. (A) and (B) accurately predicted the true FFR value of the donor artery in a coronary circulation model and explain the donor–recipient artery interaction observed in clinical practice.

Background

The pressure-derived fractional flow reserve (FFR) is a well-established index for assessing the physiological significance of coronary stenosis [1–3]. The true FFR of each stenosis should be examined after the treatment of other stenoses in patients with serial stenoses within the same coronary artery because the physiological significance of each stenosis is influenced by the other stenoses [4,5]. This is also true when the stenoses are located in different coronary arteries due to the mutual interaction between the donor artery and the recipient artery via collateral channels.

Several interventional cardiologists have reported that the FFR of the donor artery stenosis improved after recipient artery stenosis treatment in patients with multivessel coronary disease [6–10]. These reports suggest that the FFR value of donor artery stenosis is always underestimated in the presence of recipient artery stenosis. The physiology of this phenomenon cannot be explained by the current FFR theory because the coronary circulation model described by Pijls and colleagues did not include donor artery stenosis (Fig. 1A) [11]. In the present study, we mathematically derive new equations that explain the donor–recipient artery interaction and then validate them in an in vitro model of coronary circulation.

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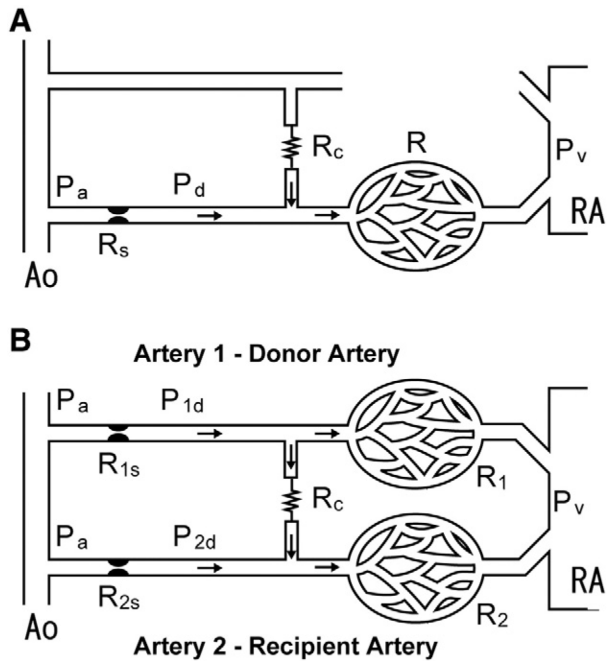

Fig. 1. (A) Schematic model representing the coronary circulation originally described by Pijls and colleagues. (B) Schematic model of the coronary circulation with a donor artery stenosis and a recipient artery stenosis. The abbreviations are the same as in the main text.

Methods

Equation derivation

Our coronary circulation model consisted of a donor artery stenosis and a recipient artery stenosis (Fig. 1B). The donor artery (Artery 1) and recipient artery (Artery 2) were then connected via collateral circulation. The abbreviations are defined as follows: R_{1s}, resistance in the donor artery; R_{2s}, resistance in the recipient artery; R_1, hyperemic microcirculatory resistance in the donor artery; R_2, hyperemic microcirculatory resistance in the recipient artery; R_c, resistance of the collateral circulation; P_a, aortic pressure; P_{1d}, pressure distal to R_{1s}; P_{2d}, pressure distal to R_{2s}; P_{1w}, coronary wedge pressure in the donor artery; P_{2w}, coronary wedge pressure in the recipient artery; and P_v, central venous pressure. This circulation model emulates a maximum hyperemic state.

The FFRs of the donor artery (FFR_1) and the recipient artery (FFR_2) are calculated as follows: $FFR_1 = (P_{1d} - P_v)/(P_a - P_v)$, $FFR_2 = (P_{2d} - P_v)/(P_a - P_v)$. The parameter calculated from $(P_w - P_v)/(P_a - P_v)$ is originally called fractional flow reserve of the collateral artery (FFR_{coll}). Later on, also the

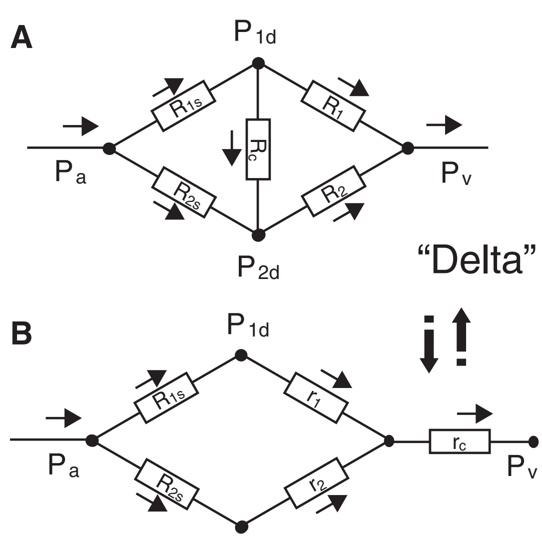

Fig. 2. (A) Electric circuit corresponding to a coronary circulation having a donor artery stenosis and a recipient artery stenosis. (B) Electric circuit obtained after the delta-star transformation. The abbreviations are the same as in the main text.