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Evaluation of Fractional Flow Reserve in Patients with coronary three-vessel disease using a simulating tool

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Abstract – Fractional Flow Reserve is an index based on pressure measurements that is clinically used to estimate whether coronary artery stenoses induce ischemia or not. In this paper, we use a simulating tool developed by our group in order to evaluate and analyze FFR values obtained in patients with three vessel disease.

Index terms - Biomechanics, Modeling, Simulation

I. INTRODUCTION

Traditionally, coronary revascularization is performed on the basis from measures of percent luminal diameter narrowing of the artery visualized at the time of invasive coronary angiography (ICA). However, some stenoses do not induce significant ischemia. That's why Fractional Flow Reserve (FFR) – or the ratio of maximal myocardial blood flow through a diseased artery to the blood flow in the hypothetical case that this artery is normal – has become a useful physiological test for assessment of the hemodynamic significance of coronary stenoses. According to the work of Pijls et al. [1], FFR may be evaluated as the ratio of the pressure distal to the stenosis to the aortic pressure. Consequently, FFR measurement is an invasive technique that requires a pressure wire to come past an epicardial stenosis. Some groups [2, 3] decided to use computational fluid dynamics and image-based modeling to non-invasively determine FFR.

We also developed a simulating tool, based on the hydraulic-electric analogy, for patients with three vessel disease (stenoses on the Left Main Coronary Artery (LMCA), on the Left Anterior Descending Artery (LAD), and on the Left Circumflex Artery (LCx), and total occlusion of the Right Coronary Artery (RCA)) (Figure 1). This model is described in details in [4] and allows to compute the pressures and flow rates everywhere in the network. This can be done in each of the four different situations of revascularization: (0G): no graft, pathological situation; (1G): one graft (Saphenous Vein Graft, on the RCA); (2G): two grafts (Internal Mammary Arteries, on the left branches); and (3G): all grafts operating (on LAD, LCx, and RCA). It is thus possible to calculate a FFR index for the LAD branch as the ratio of P_1/P_{ao} and a FFR index for the LCx branch, as the ratio of P_3/P_{ao} (P_1 is the pressure distal to the LAD stenosis, P_3 is the pressure distal to the LCx stenosis, and P_{ao} is the aortic pressure). The aim of this paper is thus to present a short analysis of the FFR values obtained for ten of the patients included in our study.

II. MATERIALS AND METHODS

All the data (clinical measurements and results of the simulations for the pressures and flow rates) for these ten patients are given in [4]. All the patients have received 3 grafts; and even with the 3 grafts, the total flow rate, Q_t, delivered to the heart remains lower than 175 ml/min in any patient.

III. RESULTS

The calculated values of FFR in the LAD branch are given in Table1, and the values of FFR in the LCx branch are given in Table2.

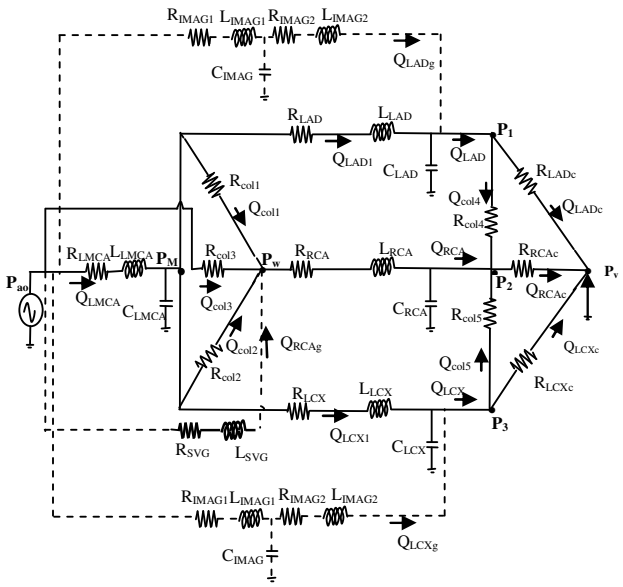

Figure 1: Analog electrical model for the coronary circulation in patients with severe stenoses on LMCA, LAD and LCx, and total occlusion of the right artery. The dotted lines represent the grafts.

N° Pat. in [4]	FFR (0G)	FFR (1G)	FFR (2G)	FFR (3G)
1	0.207	0.353	0.914	0.929
2	0.799	0.834	0.968	0.973
3	0.722	0.828	0.96	0.975
4	0.696	0.712	0.912	0.915
5	0.808	0.866	0.96	0.97
6	0.613	0.673	0.972	0.975
7	0.901	0.912	0.947	0.953
8	0.83	0.841	0.945	0.948
9	0.836	0.864	0.96	0.965
10	0.658	0.699	0.962	0.966

Table 1: Values of the FFR index for the LAD branch, in the four revascularization situations. Obtained from the simulated pressure values published in [4].

N° Pat. in [4]	FFR (0G)	FFR (1G)	FFR (2G)	FFR (3G)
1	0.817	0.885	0.962	0.974
2	0.67	0.735	0.97	0.975
3	0.356	0.476	0.932	0.941
4	0.36	0.43	0.951	0.955
5	0.6	0.658	0.916	0.925
6	0.868	0.888	0.963	0.967
7	0.829	0.848	0.95	0.956
8	0.777	0.795	0.967	0.969
9	0.854	0.872	0.925	0.93
10	0.947	0.953	0.967	0.97

Table 2: Values of the FFR index for the LCx branch, in the four revascularization situations. Obtained from the simulated pressure values published in [4].

It is commonly admitted that when FFR is higher than 0.8, the revascularization can be deferred. Following such a rule, several of our patients would not have received some graft on the LAD, or on the LCx. For example, Patient n°9 would not have receive a LAD graft, although the simulations predict a quite small amount of flow in the LAD branch for this patient (10.4 ml/min), in the case (0G).

One can also notice that very low FFR values are associated with severe stenoses. For example, Patient 1 has 26% area reduction on LMCA, 99% on LAD, and 90% on LCx. Patient 3 and 4 seem at high risk, because their FFR indexes are low on both the LAD and LCx branches.

When the right graft is operating (case (1G), all the FFR values of the left branches increase slightly, because the pressures are modified even in the left branches. But, except for the LAD branch of Patient 3, values that were previously lower than 0.8 remain lower than 0.8.

In the case (2G) and (3G), all the FFR values become higher than 0.91. This seems logical because P_1 is the pressure at the distal end of the LAD graft, P_3 the pressure at the distal end of the LCx graft, and the pressure drops in the grafts are small (a few mmHg). FFR values indicate that the better option is the case (3G). This conclusion is consistent with the one obtained through the analysis of the simulated flow rates [4]: the complete revascularization is fully justified for the 3-vessel disease patients of this study, because neither the right graft alone, nor the left grafts alone, can ensure a sufficient perfusion improvement for the heart. The left grafts mainly contribute to a better perfusion of the left territories, instead of the collateralized right region.

IV. DISCUSSION – CONCLUSION

Based on the medical follow up of the patients, clinical studies [5] have concluded that the pressure-derived FFR index is a valuable tool for decision-making in patients with complex coronary disease, especially for determining which lesions should be stented and which not. The interest of our study is that we are able to compare FFR results and quantitative data for the severity of the stenoses and for the flow rates distal to these stenoses. It appears that the critical value of 0.8 for FFR is perhaps a little low.

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