Patient's specific computer simulations to assist coronary artery bypass surgery

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We present here a simulating tool developed to compute pressure and flow rate values everywhere in the coronary network. The patients included in the study (n = 22) have very severe stenoses or even thromboses on the main coronary arteries. The model is based on the electric-hydraulic analogy, and the simulations are performed with MatLab-Simulink. Collateral pathways and bypass grafts may be included in order to see their influence on blood delivery to ischemic territories. The results obtained for the 22 patients already studied constitute a data-bank of typical cases to which the surgeons can refer. It is hoped that this can help their surgical decision for the next patients because the simulations provide some data that cannot be clinically measured.

1 Clinical context

Bypass grafting is commonly performed to obtain myocardial reperfusion distal to critical coronary stenoses or thromboses. However, the success of the intervention depends on many factors: quality of the grafts and of the anastomoses, status of the distal territory and peripheral resistances, existence of competitive flows (flow in native artery or collateral flow),… Some of these factors (peripheral resistances, collateral flows, …) are difficult to quantify precisely before the intervention. An accurate model of the coronary circulation is thus helpful for calculating the unknown quantities of interest.

The patients studied here have severe coronary disease: they have stenoses of the left main coronary artery (LMCA), left anterior descending artery (LAD) and left circumflex branch (LCx), and chronic occlusion of the right coronary artery (RCA). In this clinical situation, some collateral circulation may have developed since years to deliver blood to the ischemic right territory. Is it then necessary to revascularize the RCA? Would the strategy with only two grafts (on the left branches LAD and LCx) be the best? Will the hydrodynamic configuration after grafting favour new occlusions in the future for the patient? Will blood delivery be adequate? The model is expected to bring some answers to these questions.

2 The 0D-model

The electrical model is presented in details in [1-3]. The main arteries and the grafts are represented by a resistance, an inductance and a compliance. The value of these parameters are taken from the literature. The collateral pathways (small vessels) are represented by resistances only (R_{col}). At the end of each branch (LAD, LCx, RCA), the capillaries are represented by resistances also (R_{LADc}, R_{LCxc}, R_{RCAc}). The values of these resistances are deduced from measurements for each patient, obtained during the surgical procedure [4]. The input of the model is the aortic pressure of the patient ($P_{ao}(t)$). All the results (pressures or flow rates in any place of the network) are function of time, but mean values over several cardiac cycles may be calculated. Some of the calculated values (for example, the flows in the grafts or the pressure distal to the RCA thrombosis) can be compared to the measured clinical values. This provides an estimation of the simulations' validity.

3 Example with one Patient

The detailed results for the 22 patients are currently under publication. Informations given by the model are illustrated here with one patient of the group.

This person had previously some myocardial infarction, but no stent on any coronary artery and no diabetes. His LVEF (Left Ventricular Ejection Fraction) is 55%. The area reduction is 0% on LMCA , 99% on LAD, 100% (total obstruction) on LCx and RCA (A very severe three vessel disease). The values obtained for the resistances (R_{LADc} = 87.8 mmHg.s/ml, R_{LCxc} = 70.3 mmHg.s/ml, R_{RCAc} = 94 mmHg.s/ml , R_{col} = 480 mmHg.s/ml) are in the same range as the mean of the group (reference values given in [2]).

The simulations indicate a total amount of collateral flow around 14ml/min in the pathological situation (no graft at all) and 18.5 ml/min with the two left grafts (on LAD and on LCx). This amount of blood is delivered to the right ischemic territory, and the improvement due to the presence of the left grafts is modest. When the right graft is present, the collateral flows become rather null, or even negative. This is due to the inversion of the pressure gradient between the two extremities of the collateral pathway, and has been also found by other authors in the literature.

The simulations also show that when the left grafts are operating, the flow in the corresponding native artery decreases significantly, and this can promote progression of the disease in this artery.

In the pathological case (no graft), the flow in LAD is 0.8 ml/min ; in LCx, it is 0.01 ml/min ; in RCA, it is 18.7 ml/min. With the right graft only, these quantities become respectively 0.6 ml/min, 0 ml/min, and 50 ml/min. With the left grafts only, the values are : 41.5 ml/min, 50.1 ml/min and 11.8 ml/min ; and with three grafts (complete revascularization) : 47.5 ml/min, 58.3 ml/min and 49.5 ml/min. For this patient, the best surgical strategy was obviously to do three grafts : the sum of the flows in the three branches is improved with the grafts : it is 19.5 ml/min without any graft, 50.5 ml/min with the right graft only, 103.5 ml/min with the two left grafts only, and 155 ml/min with the three grafts. However, one can notice that even the complete revascularization does not allow to recover a normal level of heart perfusion.

The pressure drop due to each stenosis can also be obtained from the simulations. If P_M is the pressure distal to the LMCA stenosis, P_1 distal to the LAD stenosis, and P_3, the pressure distal to LCx stenosis, the ratios P_M/P_{ao}, P_1/P_M and P_3/P_M can be computed. For the patient presented here, without any graft, the values of these ratios are respectively : 0.99, 0.24, and 0.22. These ratios are similar to the classical FFR Index, except that the values have not been obtained under maximal vasodilation and that the patient presents multiple and ramified stenoses. With the three grafts, the values of P_1/P_M and P_3/P_M are very much improved (resp. 0.93 and 0.92).

4 References

[1] Maasrani, M., Verhoye, J.P., Corbineau, H. and Drochon, A. (2008). Analog electrical model of the coronary circulation in case of multiple revascularizations. *Annals of Biomed. Engin.*, 36:1163-1174.

[2] Maasrani, M., Abouliatim, I., Harmouche, M., Verhoye, J.Ph., Corbineau, H. and Drochon, A. (2011). Patients' specific simulations of coronary fluxes in case of three-vessel disease. *Jour. Biomed .Science and Engineering*, 4:34-45.

[3] Harmouche, M., Anselmi, A., Maasrani, M., Mariano, Ch., Corbineau, H., Verhoye, J. Ph. and Drochon, A. (2014). Coronary three vessel disease: hydrodynamic simulations including the time-dependence of the microvascular resistances. *Advances in Biomech and Applic.*, 1(4):279-292.

[4] Verhoye, J.Ph., De Latour, B., Drochon, A., and Corbineau, H. (2005). Collateral flow reserve and right coronary occlusion: evaluation during off-pump revascularization. *Interactive Cardiovascular Thoracic Surgery* 4:23-26.