We read the comment by Tiwari and colleagues on our negative results article [1] with interest. Herein, we would like to answer their questions in the following points:

1. De-airing of the grafts before finishing the distal anastomosis is a must and belongs to our routine as it belongs to the routine of any off-pump coronary artery bypass (OPCAB) surgery.

2. We use only CO2 blower without water insufflation. Although our group has presented our ‘simple on-site assembled blower-mister’ in 2006 [2], we found thereafter that the use of water or saline insufflations was not superior to the use of CO2 alone.

3. We know that the emboli in our article [1] were CO2 emboli simply because we used CO2 blower. We saw that the left internal thoracic artery (LITA) was full of gaseous emboli and we observed their migration – as we mentioned in our paper. We also know that, because we do not have any other logically possible source or type of these gaseous emboli.

4. It could not be possible that we experienced migration of debris or clot formation as a result of any cause. Simply the hemodynamic instability – as we also described in our paper – was temporary and had no postoperative consequences, such as high troponin levels or myocardial infarction, which is very possible in case of presence of debris or clots.

Now that we have answered their questions, we have some inquiries regarding their comment and suggestions [3]:

1. They have assumed that it is unlikely that gaseous emboli migrate in the right mammary into the left mammary. As we mentioned in our article [1], Aklog [4] has stated that the diastolic blood pressure may decrease during elevation of the apex in OPCAB surgery, and become lower than the pressure of the blower’s jet. This facilitates the migration of gaseous emboli into the coronary artery. We have to stress again that the use of the blower in our routine is well controlled regarding the flow and the distance between the blower and the coronary vessel.

2. Tiwari and colleagues support the use of oxygen blower in OPCAB surgery, yet they mentioned that it was limited in many centres due to possible fire hazards. While they state that they did not experience any complications with the oxygen blower, they fail to mention how many OPCAB surgeries are performed per year in their centre. In our article the CO2 embolization had an incidence of 0.2% (in 977 OPCAB operations) and was temporary without any intraoperative or postoperative residuals. Here, we ask the question: with this very rare self-limited complication caused by CO2 blower, could the oxygen blower be superior to the CO2 blower considering possible fire hazards?

References


eComment: Instability and collapse during off-pump coronary artery surgery – other interesting considerations

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I have read with interest the article by Badredlin et al. [1] and the eComment by Tiwari and colleagues [2]. I would like to reiterate that the possibility of conjuring bubbles with an interplay of factors like torrential flow from the leaking anastomosis, and overzealous attempts of assistant to provide a clear operative field cannot be denied. Since the microbubbles were visualised, they form a handy reason to be considered as a cause for collapse.

However, fast dissolution of CO2 does not explain the quick recovery scientifically because the dissolution of all gas bubbles in a solution is
We do agree that the comment of Dr. Sharma [1] raises very interesting considerations. Physical rules cannot be denied or neglected. Dr. Sharma questions the solubility and dissolution of carbon dioxide and gas mixture in liquids and excludes fast recovery, within minutes, in case of gaseous embolization during off-pump surgery.

However, we, as surgeons, have to match the physical rules to our clinical observations in order to reach a better understanding regarding the cause, mechanism and outcome of such complications. Explaining all haemodynamic deteriorations through kinking of the grafts might not be applicable in all cases, especially for the following reasons:

1. As Dr. Sharma himself stated [1], if this would be applicable for venous grafts, it is very unlikely to occur with arterial grafts even with decreased blood pressure during elevation of the cardiac apex. Kinking of the arterial graft is even more difficult when using T-graft technique, as in case 2 in our negative results article [2]. Figure 1 shows how the grafts are lying in full length on the ventricle in off-pump surgery.

2. In the clinical practice, in our article [2], as well as in similar publications from other surgeons [3–5], gaseous emboli were observed and recognized. However, haemodynamics were stabilized within minutes. Even in on-pump surgery, it is not rare that the surgeon observes gaseous emboli in the coronary vessels after removal of the aortic cross-clamp, yet a rise in cardiac enzymes or any other consequences that match the gaseous dissolution from 11 to 70 days (according to Epstein and Plesset’s formula) is not often. These observed emboli are definitively larger than 1 mm.

3. Going a step further, the micro-bubbles that reach the circulation during cardiopulmonary bypass and the known cavitation-effect in the blood jet coming out of the arterial cannula have no consequences that match this long time needed for dissolution.

Putting it all together, the possibility of graft-kinking is considerable but it cannot be the only explanation for all the reported cases. It cannot explain the visualized gaseous emboli within the grafts or the coronary vessels in our article or in other reports. Rules of physics must be borne in mind but the difference between in-vitro and in-vivo conditions (the blood as liquid, beating heart and coronary circulation) must be considered too. Nevertheless, the valuable comment of our colleague suggests further investigations regarding carbon dioxide emboli and its solubility in the blood during beating heart surgery.

References


eResponse: Do the rules of physics for gas solubility and dissolution match the in-vitro clinical observations during cardiac surgery?

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Governed by certain physical laws and is explained by Epstein and Plesset’s formula which considers parameters like the gas-liquid diffusion constant, universal gas constant, saturation concentration of the given gas, temperature, surface tension, and ambient pressure [3].

Air getting mixed with CO₂ during passage from blower to the coronary alters its gas coefficient unfavourably. Gas composition affects bubble elimination time in the body, since each gas has its own solubility coefficient and diffusion coefficient in a given fluid [4].

Calculating from Epstein and Plesset’s formula the diffusion time for a 1 mm bubble (presuming the average coronary artery size is 2 mm) is from 11 days to 70 days [5]. Even if faster absorption of CO₂ vis-à-vis air is considered recovery of hemodynamic status within a few minutes is unlikely, more so because, contrary to popular belief, emboiled gas does not travel to veins through capillary bed [5].

Early normalisation and lack of rise of cardiac enzymes also rule out the distal embolisation of debris contrary to the suggestion by Tiwari and colleagues.

The most likely explanation seems to be kinking of the grafts. This appears likely because in both cases the lifting of the heart was associated with the collapse. Other operators have also reasoned on similar lines. Manipulation of the heart may cause hypotension or traction on newly constructed grafts, which can cause sudden reduction of flow; although kinked arterial grafts are less responsible than kinked venous grafts more vigilance has been suggested. Though these manoeuvres do not cause ECG or haemodynamic problems in one-third, they have resulted in myocardial ischemia, cardiovascular collapse, and conversion to cardiopulmonary bypass in others. Further, it is pertinent to consider the importance of stunning and reperfusion which undoubtedly play an important role in off-pump surgery also.

References


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