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Perfusion and Aortic Surgery: Patient Directed Cardiopulmonary Bypass and Quality Improvement

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Abstract: Aortic surgery frequently extends the boundaries of perfusion knowledge learned from non aortic cardiac surgery. This is due to the extremes of temperature, prolonged bypass times, hypothermic arrest, and selective organ(s) perfusion. Suboptimal perfusion can potentially affect outcomes even after technically successful aortic surgery. We present the concepts of patient directed bypass with regard to blood pressure, flow during cardiopulmonary bypass (CPB), oxygen delivery, cooling, and carbon dioxide levels on bypass. Quality of perfusion during aortic surgery is then addressed in the context of Perfusion Standards of Reporting Trials (PERFSORT, www.perfsort.net). PERFSORT analyses these variables during bypass: blood pressure, hematocrit, lactate, glucose, and temperature, all of which are known to affect outcomes. PERFSORT can be applied to individual cases or a series, and although primarily designed for research publications, is equally useful in a purely clinical setting. A new concept from engineering called Lissajous figures is then discussed to potentially retrospectively assess the effects of ischemia during aortic surgery. This may help identify why some patients despite flawless surgery, anesthesia, and perfusion, in the absence of bleeding, stroke, and obvious causes of organ damage at the time of aortic surgery develop multi organ dysfunction. **Keywords:** perfusion, Lissajous figures, aortic, aortic arch, selective cerebral, cardiopulmonary bypass. *JECT. 2011;43:P68–P71*

OVERVIEW

Organ perfusion during bypass is vital to a good outcome after technically successful aortic surgery. Patient directed bypass via optimization of blood pressure, flow during cardiopulmonary bypass (CPB), oxygen delivery, cooling, and carbon dioxide levels on bypass may help to reduce morbidity and potentially mortality. Quality improvement in aortic surgery perfusion in clinical practice and the research setting is then discussed. Quality improvement via a concept from engineering called Lissajous figures is discussed to semi quantify the effects of ischemia during aortic surgery, potentially helping to improve patient outcomes.

PATIENT DIRECTED BYPASS

Blood Pressure

The DC (direct current, non pulsatile) equivalent voltage of an AC (alternating current, pulsatile) voltage can be calculated via the term root mean square (1). By analogy, the nonpulsatile equivalent blood pressure on bypass of a pulsatile blood pressure (prebypass) can be calculated via the term root mean square. Using the standard medical formula for calculation of mean blood pressure, a potential underestimation of perfusion pressure by 12 mmHg is possible, in a normotensive subject (128/58 mmHg), if the medical mean was used as your reference point (Figure 1) (2).

Flow

Organ ischemia secondary to hypoperfusion occurs in some patients during bypass. Patients undergoing aortic surgery are especially prone to this. Selective cerebral perfusion and lower body perfusion were introduced to try and reduce the incidence of organ ischemia during aortic arch surgery. If the flow during bypass was matched to the preoperative resting state then the chance of organ ischemia may be lessened if the perfusion pressure and hematocrit are correct as well.

With the widespread introduction of magnetic resonance imaging for elective aortic surgery to assess anatomy, an opportunity exists to non-invasively assess cardiac output and relevant flows for selective cerebral and lower body perfusion.

Magnetic resonance imaging has previously been validated as an accurate tool to assess cardiac output and flow in arteries (3). Figure 2 demonstrates typical flow data on a patient.

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Oxygen delivery

Reduced oxygen delivery as a cause of increased renal dysfunction following cardiac surgery is widely accepted as being generally true (1). So far comparative work has not been performed in aortic surgery. Oxygen deficiency in aortic surgery can be revealed when excessive desaturation in venous return occurs on reperfusion, due to increased oxygen uptake. A typical case is shown in Figure 3. Blood pressure, flow and hematocrit, and temperature are all important variables that are recorded by the PERFSORT (www.perfsort.net) system.

Cooling

Little consensus exists as to the temperature to cool to on bypass for surgery involving the aortic arch. Every surgeon cools to a different temperature for a given operation, especially so for potential circulatory arrest cases (4). Excessive cooling and thus prolonged rewarming increases total CPB time, potentially increasing the inflammatory reaction, platelet, and coagulation disorders and increasing organ ischemia (5,6). However, inadequate cooling renders organs, particularly the brain, susceptible to irreversible ischemic insult (7).

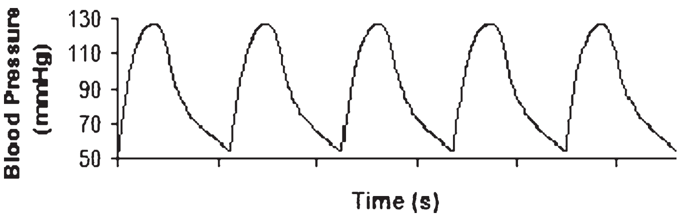

Figure 1. Typical blood pressure trace 128/58 mmHg, medical mean 81 mmHg, root mean square pressure 93 mmHg.

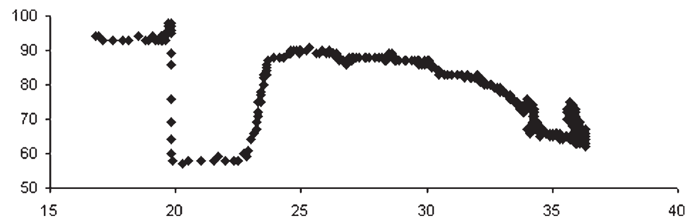

Figure 3. Typical mixed venous oxygen desaturation (y axis) verses temperature (°C × axis). Desaturation secondary to increased oxygen extraction is because of organ ischemia due to reduced oxygen delivery.

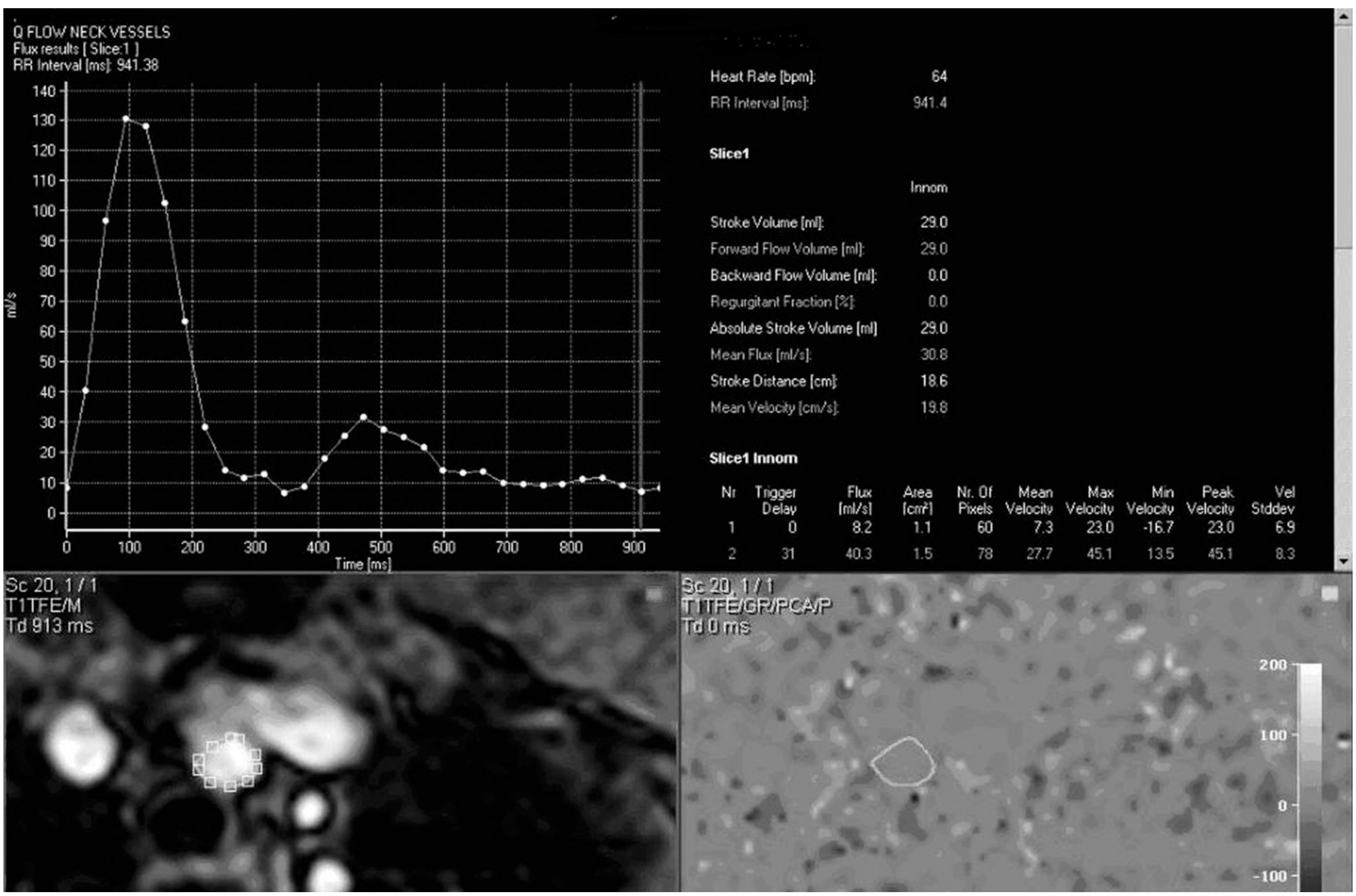

Figure 2. Typical MRI data on cardiac output, selective cerebral blood flow and lower body blood flow for femoral artery cannulation with a cross clamped distal arch.

To date frequently no account of individual patient variation is involved in the decision as to what temperature to cool to. Figure 4 demonstrates the variability in temperature at which oxygen extraction ceases in a small series of aortic surgery cases involving circulatory arrest.

Carbon Dioxide Levels during Bypass

The debate between pH stat and alpha stat hinges on carbon dioxide management and levels during CPB (8–12). As carbon dioxide level during bypass is so important, it seems surprising that there seems to be so little attention to arterial carbon dioxide levels during CPB. Furthermore, no consideration of patient pre procedural arterial carbon dioxide levels are currently accounted for during routine CPB, despite the evidence available in the literature documenting a wide variation between individual arterial carbon dioxide levels in health (13) and disease. The variability of carbon dioxide on bypass typical of a large unit (Liverpool Heart and Chest Hospital) is shown in Figure 5.

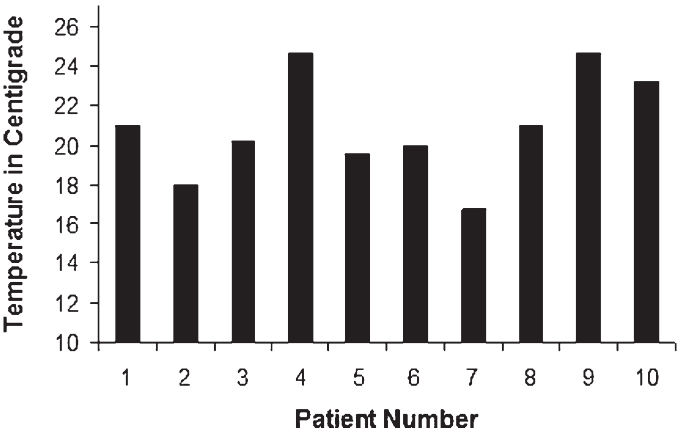

Figure 4. Variability in temperature at which oxygen extraction ceases in a small series of aortic surgery cases involving circulatory arrest.

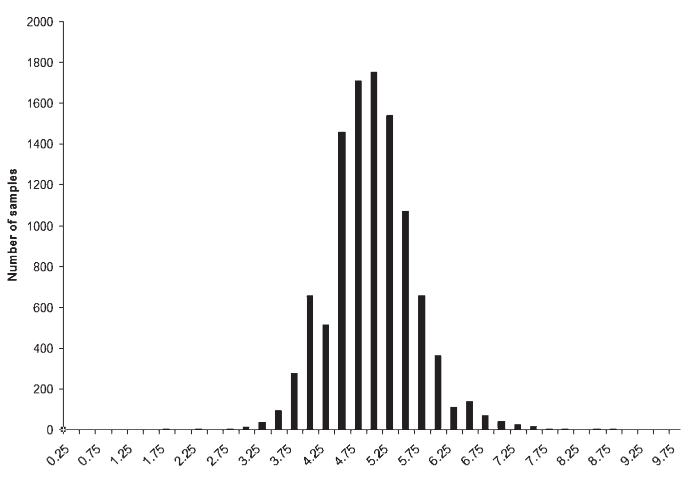

Figure 5. Typical carbon dioxide levels during cardiopulmonary bypass. (Normal range 3.5–5.5 KPa).

QUALITY IMPROVEMENT IN AORTIC PERFUSION

Individual Cases and Case Series and the Scientific Literature

The fundamental importance of blood pressure, glucose, temperature, lactate, and hematocrit are not debated. The cut off levels that are deemed significant and how to manage them are highly controversial, however. As no cut off levels have so far been described or universally agreed, the PERFSORT (www.perfsort.net) initiative merely describes the equipment used and lists the perfusion variables (14). This allows latter analysis, should cut off values for these variables become accepted—backward compatibility.

We encourage you to visit http://www.perfsort.net/study_detail.asp?id=51 and download the excel file at the bottom of the page to view a typical perfsort data file on a small series of patients. Quality markers calculated by PERSORT include:

Blood pressure:
Percentage of time < 40, 50, 60, 70 mmHg
SD of percentage of time for each pressure

Hematocrit:
Average of minimum
Average of maximum
Average
SD of minimum
SD of maximum

Temperature:
Average of maximum
SD of maximum

Glucose:
Average of minimum
Average of maximum
Average
SD of minimum
SD of maximum
SD of average

Lactate:
Average of maximum
SD of maximum

Root Cause Analysis in Aortic Surgery

Root cause analysis (RCA) is a class of problem solving methods aimed at identifying the root causes of problems or incidents. The practice of RCA is predicated on the belief that problems are best solved by attempting to correct or eliminate root causes, as opposed to merely addressing the immediately obvious symptoms.

Root cause analysis requires impartiality and profound knowledge on the topic in hand. All too frequently the role of perfusion, myocardial protection, cerebral damage, and bleeding are not factored into an analysis of death post aortic surgery.

Lissajous Figures

Only after the fundamental principle mentioned above has been addressed can the technique of Lissajous figures be potentially used. A Lissajous figure is a technique in electrical engineering to compare two different electrical signals (15). One signal is plotted on the x axis and the other on the y axis, with the parameter of time connecting the x and y axis values. Utilizing this basic concept in a very simple manner, nasopharyngeal temperature and mixed venous oxygen saturations can be plotted to potentially identify organ ischemia which may help to explain why some deaths/morbidities occur. Figure 3 demonstrates this and is in fact a Lissajous figure.

SUMMARY

Patient directed bypass with regard to flow, pressure, hematocrit, oxygen delivery, and carbon dioxide may help reduce the detrimental effects of cardiopulmonary bypass in patients undergoing aortic surgery. The potential for the technique of Lissajous figures to effect outcomes is interesting but unproven. Perfusion quality in aortic surgery for an individual case, a series, or in the scientific literature may be further improved with the use of PERFSORT initiative.

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