

Lissajous Figures: An Engineering Tool for Root Cause Analysis of Individual Cases—A Preliminary Concept

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Abstract: Some patients have short intensive care stay periods and little or no organ dysfunction after cardiac surgery and others do not despite seemingly faultless surgery, perfusion, and anesthesia. These “unknown” reasons for death and morbidity usually relate to organ ischemia and inflammation, but are obviously multifactorial. A Lissajous figure is a technique in electrical engineering to compare two different electrical signals. We utilize this basic concept in a very simple manner to potentially identify why some of these unknown deaths or morbidities occur. Utilizing an electronic perfusion database, we retrospectively analyzed 43 patients undergoing aortic surgery with regard to central venous saturations during cooling and rewarming. Isolated aortic valve replacement patients were excluded. Central venous saturation, time, and temperature were plotted to create a Lissajous figure for the whole operation, and during cooling and rewarming separately. Temperature and saturations were

analyzed every 20 seconds. Perfusion related variables were registered and uploaded to www.perfsort.net. Lissajous figures during cooling add little to patient care due to their similarity. Isolated rewarming revealed startling differences. It is immediately visually obvious who had short and long periods of tissue ischemia and reperfusion during rewarming in a seemingly uneventful operation. The periods of ischemia can be semi quantified into: none, mild, moderate, and severe. Creation of simple Lissajous figures during rewarming for bypass runs may be an additional helpful tool in root cause analysis of patient death/morbidity when surgery, perfusion, and anesthesia seemed faultless. Low central venous saturations at hypothermic temperatures mean significant metabolic activity, indicating tissue ischemia is occurring. Further work is needed to correlate this concept to outcomes. **Keywords:** cardiopulmonary bypass, Lissajous figures. *JECT. 2011;43:153–156*

Some patients seem to have short intensive care stay periods and little or no organ dysfunction after cardiac surgery and others do not despite seemingly faultless surgery, perfusion, and anesthesia. These “unknown” reasons for death/morbidity usually relate to organ ischemia and inflammation, but are obviously multifactorial.

Mixed venous saturations during cardiac surgery can be utilized as an index of systemic oxygen delivery (1). Cooling remains central to reducing tissue oxygen requirement due to the biochemical concept of Q_{10} (2).

The introduction of electronic data management (EDM) systems enables accurate and detailed collection of perfusion information. Prior to this, recorded information was infrequent and subjected to error and bias by clinicians. Electronic acquisition systems make it possible to capture hundreds of variables as frequently as every 20 seconds with great accuracy. The concept in this paper is only possible with EDM.

A Lissajous figure is a technique in electrical engineering to compare two different electrical signals (3). 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. We utilize this basic concept in a very simple manner. Nasopharyngeal temperature and mixed venous oxygen saturations are plotted to potentially identify organ ischemia which may help to explain why some deaths/morbidities occur.

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METHODS

Utilizing an electronic perfusion database, we retrospectively analyzed 43 patients undergoing aortic surgery (with or without circulatory arrest) with regard to mixed venous saturations during cooling and rewarming. Operations included: aortic root with open distal anastomosis ($n = 31$), thoracoabdominal aneurysm repair ($n = 4$), Davids procedure with open distal anastomosis ($n = 2$), aortic dissection ($n = 2$), hemi arch replacement ($n = 2$), ascending aorta replacement ($n = 1$), and total arch replacement ($n = 1$). Isolated aortic valve replacement patients were excluded.

All cases were performed with a Sorin centrifugal pump (Sorin Group, Milan, Italy), Medtronic arterial and venous cannula (Medtronic, Minneapolis, MN), Maquet arterial line filter (Maquet, Wayne, NJ), alpha stat, and a combination of antegrade and retrograde cold blood (4°C) cardioplegia. In-line arterial and venous blood saturations were monitored, and temperature was defined as nasopharyngeal. Mixed venous saturation, time, and temperature were plotted to create a Lissajous figure for the whole operation, and cooling and rewarming separately. Perfusion related variables were registered and uploaded to www.perfsort.net.

Data Source and Processing

Data was extracted from the Maquet JOCAP data management system. Mixed venous oxygen saturations, temperature, and time values were extracted into Excel[®] (Microsoft Corporation, Redmond, WA) format for processing. Five graphs were constructed for each patient:

Non Lissajous Figures:

Temperature versus time
Saturations versus time

Lissajous Figures:

Mixed venous saturations versus temperature
Cooling—Mixed venous saturations versus temperature
Rewarming—Mixed venous saturations versus temperature

RESULTS

PerfSORT Compliance Statement

Study Number: P00047. PerfSORT Compliance Version 1:

Tier 1 Compliance: 100% (blood pressure, temperature, hematocrit, glucose, lactate)
Tier 2 Compliance: 80% (equipment and bypass)

For further details of perfusion data please go to <http://www.perfsort.net>.

Data Processing

The Excel[®] datasheet utilized to create the Lissajous figures is available for free download at www.mpoullis.com/lissajous.xls.

Temperature versus Time (non Lissajous Figure)

This was utilized to aid easy identification of the minimum temperature that occurred during a case. A typical profile is shown in Figure 1, identifying a minimum temperature of 10°C .

Mixed Venous Oxygen Saturations versus Temperature (Lissajous Figure)

It can be seen from Figure 2, a typical case cooled to 18°C , that it is impossible to discern what is happening due to cooling and rewarming points overlapping. Utilizing the minimum temperature from Figure 1, the data from Figure 2 was broken down into cooling and rewarming figures.

Cooling—Mixed Venous Oxygen Saturations versus Temperature (Lissajous Figure)

Cooling was very predictable with the mixed venous saturations all slowly rising to 100% as oxygen extraction decreased on cooling. A typical case is shown in Figure 3. It can be seen that cooling results in an increase in mixed venous saturations due to decreased metabolic requirement due to the Q_{10} phenomenon (2), but constant oxygen delivery. Lissajous figures during cooling seems to add little additional information towards patient care.

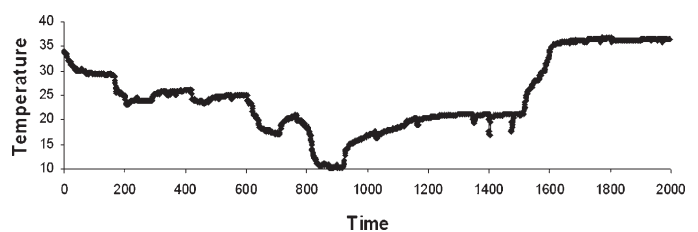


Figure 1. Temperature versus time for a whole operation.

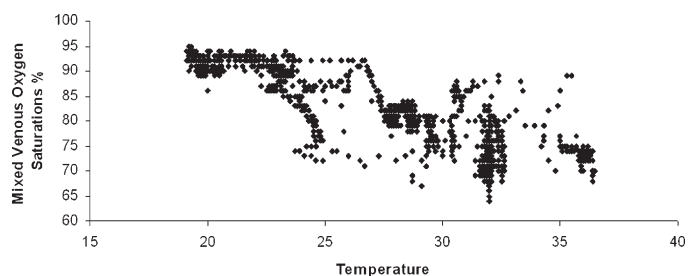


Figure 2. Mixed venous oxygen saturations versus temperature for a whole operation.

Rewarming—Mixed Venous Oxygen Saturations versus Temperature (Lissajous Figure)

Rewarming when graphed separately to cooling revealed startling differences (Figure 4). Tissue ischemia is implied due to deep drops in central venous oxygen saturations at low temperature, implying metabolic activity to replenish ischemic organ beds. Without any statistical analysis, it is immediately visually obvious who had short and long periods of tissue ischemia and reperfusion during rewarming in a seemingly uneventful operation.

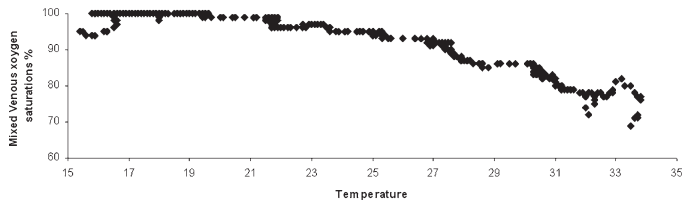


Figure 3. Cooling—saturations versus temperature.

Mixed Venous Oxygen Saturations versus Time (non Lissajous Figure)

This is utilized to identify when in the operation organ ischemia has been revealed (Figure 5).

DISCUSSION

Creation of simple Lissajous figures during rewarming for bypass runs may be an additional helpful tool in root cause analysis of patient death/morbidity due to unexplained organ failure post major aortic surgery, when surgery, perfusion, and anesthesia seem faultless. A simple graphical representation of the large amounts of electronic perfusion data on mixed venous saturation and temperature that is generated during prolonged cases may aid analysis.

Mixed venous oxygen saturation should not be confused with central venous oxygen saturation, as the latter is prone

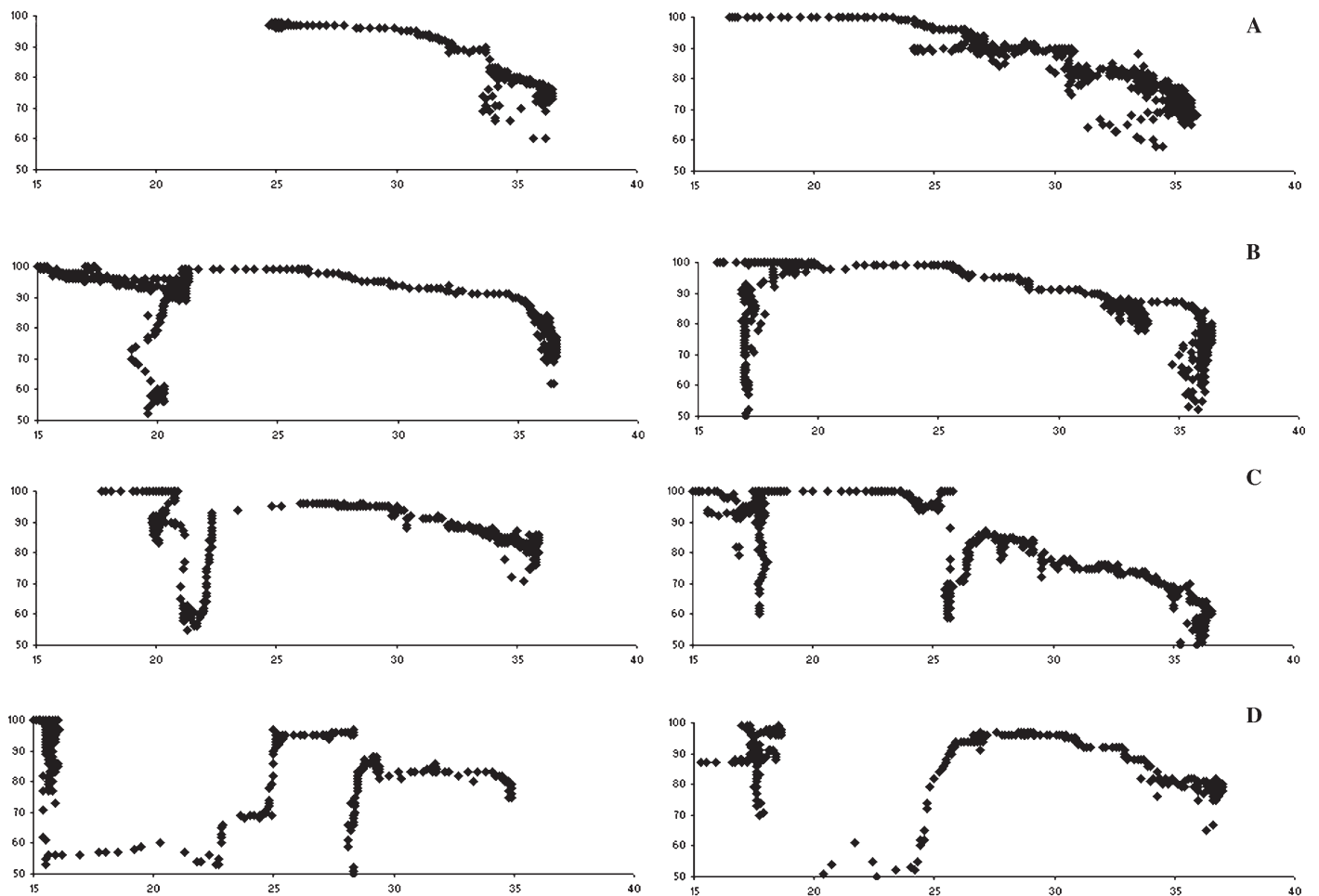


Figure 4. A selection of rewarming curves demonstrating marked variation in organ ischemia. Temperature is on the x-axis, and mixed venous saturations on the y-axis. (A) None, (B) mild, (C) moderate, and (D) severe desaturations at low temperatures are demonstrated.

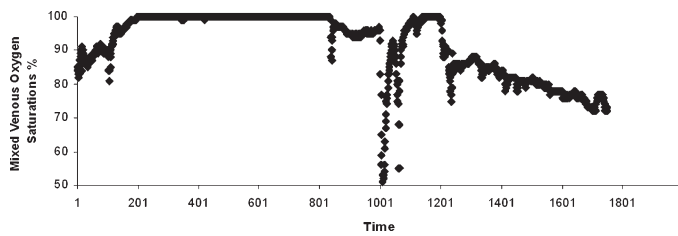


Figure 5. Mixed venous oxygen saturations versus time.

to mixing errors due to variations in the oxygen saturation of blood in the inferior and superior vena cava (4). During bypass, the mixed venous saturation is measured at the pump, so this error is unlikely to be present in our data.

Mixed venous blood in a normal patient at rest is about 75% saturated. As a general rule, any condition that leads to a sustained mixed venous saturation of less than 50% implies significant organ ischemia (5). Low central venous saturations at hypothermic temperatures mean significant metabolic activity, indicating tissue ischemia is occurring (6). The cause of the ischemia is multifactorial and was not analyzed in this concept paper; however the fact that some patients clearly had ischemia occurring during rewarming is clear for the graphs.

Identification and recognition of ischemia during aortic cases may enable strategies to minimize its occurrence such as lower body perfusion, selective arterial perfusion, and minimization of circulatory arrest periods. We have not tried to quantify the ischemic insult, but parameters such as blood pressure, oxygen delivery, lactate, and maximum oxygen debt may be reasonable quantitative initial surrogate measurements, but clinical validation is needed.

Electroencephalogram monitoring is utilized by some groups prior to circulatory arrest; however some have reported electrical neutrality despite continuing oxygen extraction implying residual metabolic activity (7). This means reperfusion will be associated with desaturation as the oxygen debt is repaid. Organ damage is probably highly variable in this setting depending on numerous factors such as total oxygen debt, ischemic time, and manner of perfusion. Unfortunately, this technique is only of use retrospectively, as once central venous desaturation has occurred, by definition ischemia has already occurred.

Ischemia and inflammation are intertwined. Ischemia causes organ inflammation on reperfusion (8) and inflammation can cause organ damage via ischemia (9,10). Ischemic organ damage secondary to suboptimal bypass may potentially be addressed by the use of PerfSORT (www.perfsort.net). The importance of tissue perfusion as an initiating factor with regard to inducing inflammation is the basis of the consensus statement on inflammation and cardiac surgery (11).

Organ ischemia is multifactorial. Numerous factors are potentially important: perfusion and oxygen delivery on

bypass (12), myocardial protection eliminating the use of intra aortic balloon pumps and inotropes, lack of bleeding and blood and coagulation factor transfusion, little use of vasoconstrictors to maintain blood pressure, and atherosclerosis in feeding vessels (12,13). Prior to the use of Lissajous figures, adherence to the quality markers of PerfSORT should be analyzed (14).

Limitations

Our sample size was too small, and operative variables too numerous to dissect out the true use of this technique to try to explain the “unexplained multi organ failures” that occur after aortic surgery. Further work is needed to correlate this concept to outcomes, mortality, multi organ failure, and length of intensive care stay.

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