

# A novel versatile concept of cardioplegia delivery in cardiac surgery: The ReverseTWO cardioplegia circuit system

Perfusion  
2023, Vol. 0(0) 1–6  
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DOI: [10.1177/02676591221150168](https://doi.org/10.1177/02676591221150168)  
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## Abstract

Nowadays, the necessity of having a cardioplegia circuit capable of being adapted in order to administer different types of cardioplegia is strategically fundamental, both for the perfusionist and for the cardiac surgeon. This allows to avoid cutting tubes, guarantees sterility and, most of all, limits the number of cardioplegia circuits for the different strategies of cardiac arrest. The novel “ReverseTWO cardioplegia circuit system” is the development of the precedent “Reverse system” where mainly the 4:1 and crystalloid cardioplegia were used. It has the advantage of allowing immediate change of cardioplegia set-up versus four types of cardioplegia technique, when the strategy is unexpectedly changed before the beginning of cardiopulmonary bypass (CPB), is safe and enables the perfusionist to use one single custom pack of cardioplegia. Two pediatric roller pumps are usually used in our centre for cardioplegia administration; they have a standardized calibration (the leading with ¼ inch and the follower with 1/8 inch) and the circuit consequently has two different tube diameters for the two different pumps. The presence in the circuit of two different shunts coupled with two different coloured clamps allows the immediate set-up for different cardioplegia administration techniques utilizing a colour-coding mechanism. The aim of this manuscript is to present the new ReverseTWO Circuit. This novel system allows to administer four different cardioplegic solutions (4:1, 1:4, crystalloid, ematic) based on multiple tubes, which can be selectively clamped, identified through a color-coding method. The specificity of this circuit is the great versatility, which leads to numerous advantages, such as reduced risk of perfusion accident and reduced costs related not only to the purchase of different cardioplegia kits but also to the storage. <https://youtu.be/ovjBE4ok2Ds>

## Keywords

Cardioplegia, myocardial protection, cardioplegia circuit, cardiac surgery, cardiopulmonary bypass

## Introduction

Cardiac surgery procedures usually when required, involve the use of cardiopulmonary bypass (CPB) and cardiac arrest. As a consequence, myocardial protection is essential. Despite the widespread use of cardioplegia, debate over the best technique remains ongoing. Cardioplegia (CPL) composition (crystalloid vs blood), temperature and sites of injection have been extensively researched. However, regardless the amount of literature on the subject, the optimal approach is far from being identified.

The goal of myocardial protection is to maximize the functional recovery after cardioplegic cardiac arrest and

to minimize the extent of ischemia-reperfusion injury. Therefore, there is no guarantee that a single strategy can be safely applied to all patients, in all circumstances. Furthermore, choice is frequently dependent on

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surgeon's preference, and some surgeons might prefer the comfort of a single-shot CPL administration, while others may feel more confident following the widespread multidose CPL protocol. The latter technique further poses the issue of re-dosing intervals. A common and intuitive idea is that shorter re-dosing intervals may lead to improved myocardial protection. However, this has not been proven in the literature and standard intervals vary approximately between 20 and 30 minutes.

Buckberg<sup>1</sup> was the first CPL utilized in our experience, approximately 30 years ago, when the great majority of surgeries performed were coronary artery bypass grafts (CABG). Subsequently, as an alternative, for a short period of time, Calafiore CPL<sup>2</sup> was employed. With the following increase in mitral valve minimally invasive surgeries,<sup>3,4</sup> a shift towards a greater use of Bretschneider HTK (SALF, Italy) occurred<sup>5</sup> and the Reverse CPL circuit was developed.<sup>6</sup> ReVerse CPL circuit allowed the administration of two different types of CPL thanks to a single shunt between two pediatric roller pumps and to a single clamp in it.

Furthermore, in the last months, Del Nido CPL (Galenica Senese, Italy) was introduced mainly for cross-clamping less than 90 minutes.

This great variability led us to the idea behind the development of a novel system, the ReverseTWO circuit, capable of administering three or more different cardioplegic solutions based on two shunts, identified through a clamp color-coding method. The advantage of this circuit is the great versatility: it has two different tubes for two different pumps (1/4 and 1/8 inch) and the assembly is standardized. There are two shunts equipped with colored clamps (blue and red) that permit the communication between the pumps in order to administer different types of CPL only by closing the colored clamp.

Another clamp (white) is placed in the line that takes blood from the oxygenator.

Colored clamps have been created in order to identify different types of cardioplegia and the colour-code is inserted in the checklist.

## Novel technique and design

The standard CPB machine used at our institution is a S5-roller pump (Stockert, Germany), centrifugal pump when required (CP5, LivaNova),

3T Heater-Cooler systems (LivaNova) are commonly used and chemical treatment is applied.<sup>7</sup> Custom adult circuits with phosphorylcholine-coated tubing (LivaNova, Mirandola, Italy) with an open reservoir are employed. The circuit is primed with 1500 mL-lactate

ringer, 250 mL of 18%-mannitol solution and 5000 UI of heparin. Systemic heparinization is achieved with 300 UI/kg heparin and an adequate activated by kaolin clotting time, with an ACT superior to 480 s (ACT Plus Medtronic), is maintained with additional boluses if necessary. At the end of CPB, heparin is reversed with protamine sulfate infusion with ratio 1:1. Pump flows are generally maintained at 2.0–2.4 L/min/m<sup>2</sup> based on patient's BSA, with a mean arterial pressure above 60mmHg. Gravitational drainage is generally used in all patients (through 1/2- and 3/8-inch tubing) with the exception of peripheral cannulation, which requires vacuum-assisted venous drainage.<sup>8</sup> CPL circuit is connected to CPB circuit: the CPL blood line takes blood directly from the oxygenator.

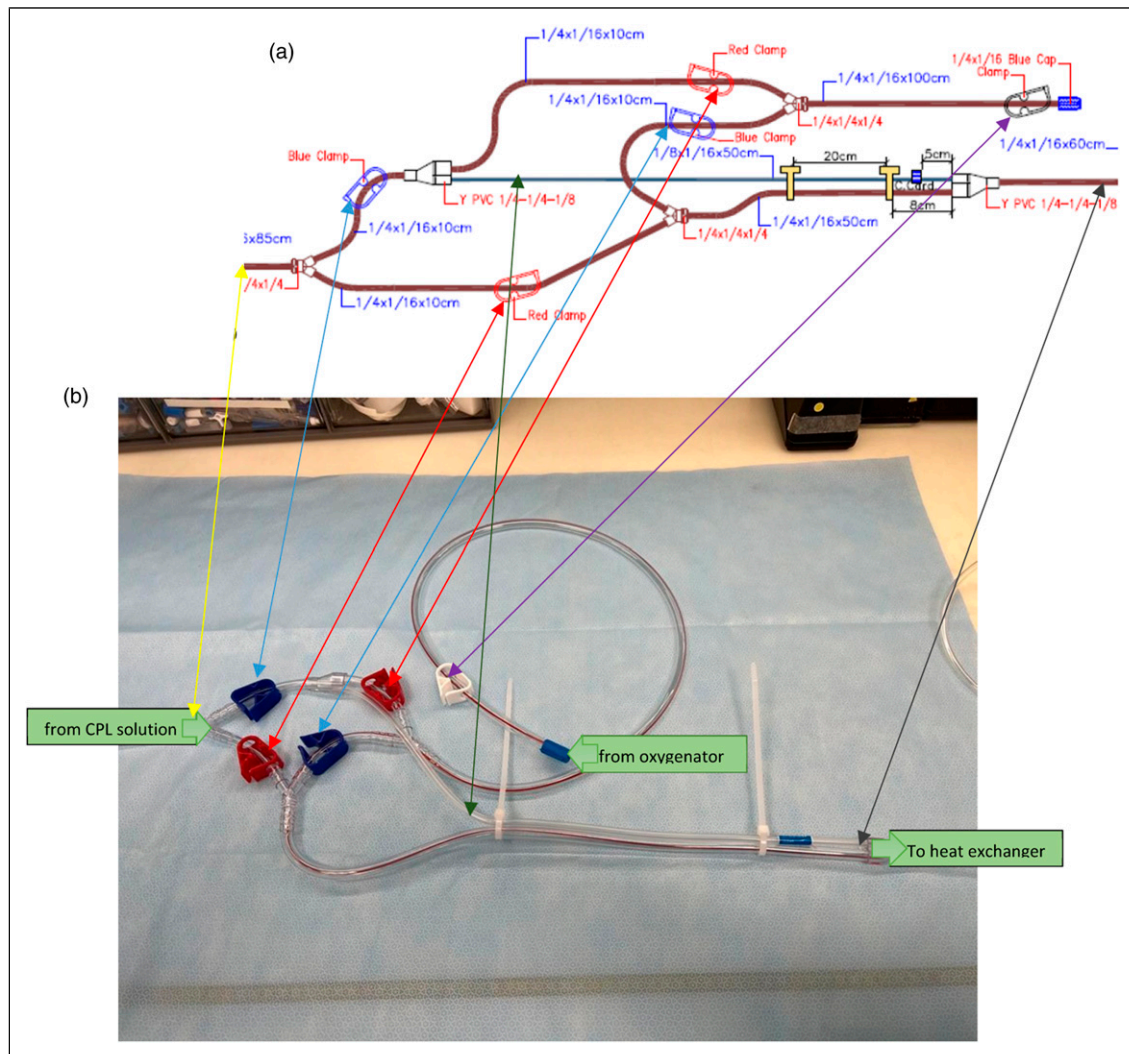
In our Institution, three different cardioplegic solutions are currently available:

- *Buckberg cardioplegia*<sup>1</sup> (BIEFFE Medital Baxter, Italy) is a mixed blood-crystalloid solution in a 4:1 ratio. It is a potassium-rich extracellular cardioplegic solution that acts through stabilization of the cell membrane potential and is generally administered as repeated infusions.<sup>9</sup>
- *Bretschneider HTK* (SALF, Italy) is a crystalloid solution, generally administered as a single infusion and guarantees a longer time (3 hours) of protection from ischemia.<sup>10</sup> Its main application is for longer duration surgeries.
- *Del Nido cardioplegia*<sup>11</sup> (Galenica Senese, Italy) is an extracellular solution mixed with autologous blood, with a blood to crystalloid ratio of 1:4. It was initially employed for pediatric cardiac surgery and then subsequently used for adult cases as well. It can be employed in cases with a potential X-clamp duration of less than 1.5 hours.

The previous design named "ReVerse" CPL circuit has been previously described.<sup>6</sup> The main difference with the ReverseTWO circuit is that the novel system allows delivery of four than two types of CPL (precedent version called Reverse), thanks to an additional shunt and additional clamps.

The custom disposable single CPL circuit is described both by a technical design (Figure 1(a)).

As previously described, It mainly consists of a loop with tubings of two different sizes (1/4-inch for the master pump and 1/8-inch for the slave follower pump), with different colour clamps, a heat exchanger with a temperature monitoring port, a stopcock to allow circuit flushing and a pressure isolator in order to monitor the pressure of cardioplegia infusion.



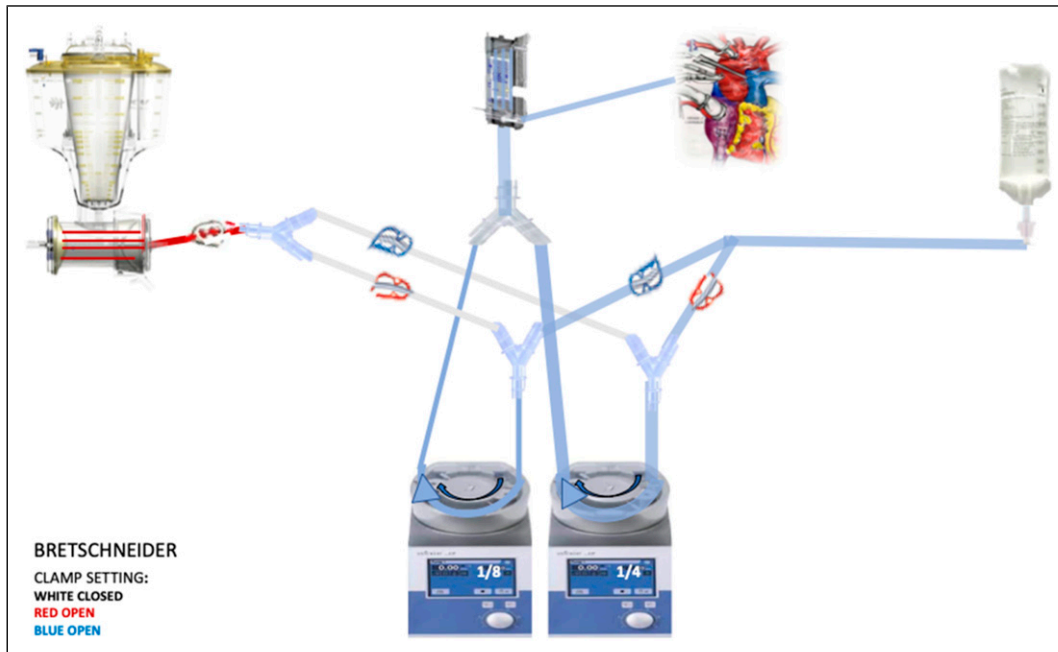
**Figure 1.** (a): The ReverseTWO design; (b): Loop with colored-clamp code. The yellow arrow show the line from the crystalloid CPL solution; the green arrow show the 1/8 inch line; the purple arrow show the line from oxygenator, the white clamp is closed during crystalloid CPL administration and opened in all other cases; the black arrow show the line versus the heat exchanger; the blue and red arrows show the colored clamp were fundamental for ReverseTwo CPL.

The total length of the CPL circuit (Figure 1(a)) is considered from the spikes at the end of the sterile line, therefore 4.1 meters of 1/4-inch tubing with the exception of 70 cm of 1/8-inch tubing. This is extremely important in order to calculate the effective administration of CPL. In fact, the total priming, from the spikes to the end of the sterile line is 220 mL. However, when considering the different types of CPL, the priming differs. For Del Nido CPL (Figure 3), with a CPL to blood ratio of 4:1, the total priming from one spike to the end of the sterile line is 151 mL; on the contrary, for Buckberg CPL (Figure 4), with a blood to CPL ratio of 4:1, the total priming accounts for 156 mL.

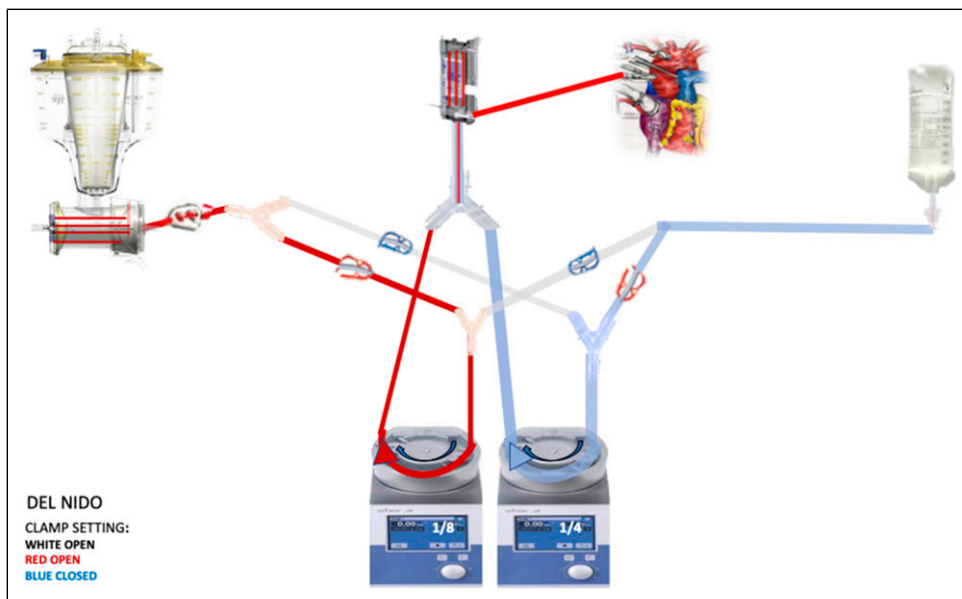
Usually, in our experience, during Buckberg administration, two separate pediatric roller pumps are

utilized to infuse CPL, a master pump and a slaved pump; for the main pump a 1/4-inch tubing line is used that transports blood from the oxygenator, while an 1/8-inch tube is used for the slave pump and this line transports CPL. Blood and CPL are then mixed before the heat exchanger. When crystalloid (Bretschneider) is requested, the main and slave pumps are used together to obtain CPL administration. However, in order to administer Del Nido CPL, that has an inversely proportional blood-to-CPL ratio with respect to Buckberg CPL, another modified circuit was necessary and the Reverse circuit could not be used.<sup>6</sup>

The ReverseTWO system circuit (Figure 1) consists in:



**Figure 2.** Modification of ReverseTWO circuit when Bretschneider cardioplegia is administered. <https://youtu.be/XjSM9gM80V0>



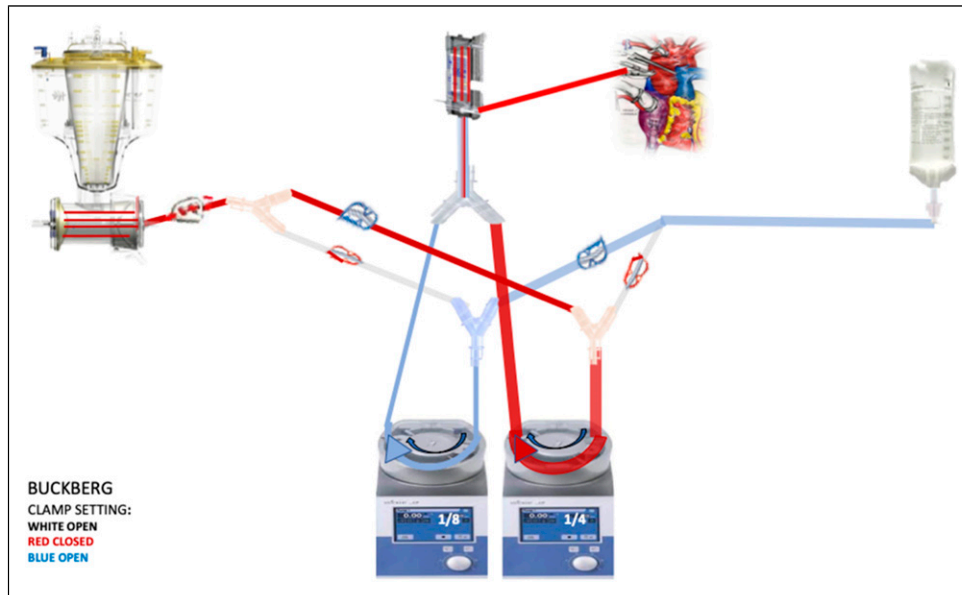
**Figure 3.** Modification of ReverseTWO circuit when Del Nido cardioplegia is administered. <https://youtu.be/mdDPaXV5jsw>

- Two 1/4-inch lines leave the CPL solution through a Y connector; the one with the red clamp is directed towards the main roller pump, while the one with the blue clamp is directed towards the slave pump.
- One 1/4-inch line leaves the oxygenator; then through a Y connector it divides into two 1/4 inch lines: the one with the red clamp is directed

towards the slave pump, while the other with the blue clamp towards the main roller pump.

This system created with colour-coded clamps allows immediate identification of the exact direction of blood flow and CPL infusion (Figure 2, 4 and 4), allows prompt switching from 4:1 to 1:4 CPL administration and permits to use different techniques of CPL





**Figure 4.** Modification of ReverseTWO circuit when Buckberg cardioplegia is administered. <https://www.youtube.com/watch?v=XaxvLcjM5ME>

administration without changing the double pediatric pump setting. This system allows to choose the CPL solution also a few minutes before starting the intervention, so the surgeon can decide the best technique for myocardial protection.

When Bretschneider crystalloid CPL is employed (Figure 2), the white clamp needs to be closed, while both red and blue clamps are left open and this allows both pumps to infuse crystalloid CPL. It is generally administered as a single infusion of cold CPL.

It is also possible to deliver only blood CPL by opening the white clamp (near the oxygenator) and excluding the line from the CPL bag. The entire circuit is filled with blood and through the stopcock anything can be added, such as potassium. Furthermore, through the heat exchanger the blood temperature can be controlled.

In case Buckberg CPL is used (Figure 3), its delivery through the ReverseTWO circuit is gained by closing the red clamps and opening the blue and white ones. This allows for the blood line to shift to the 1/4-tube roller pump and CPL to flow in the 1/8-tube roller pump.

When Del Nido CPL is used (Figure 4), the blue clamps are closed and the red and white ones opened. Blood flows to the 1/8-line roller pump while CPL shifts to the 1/4-tube roller pump. The prime line is rapidly filled and approximately 150 mL of CPL solution is added to the 1200 mL bag of Del Nido solution. Generally, 1 L of solution is sufficient; however, in order to guarantee that the entire amount is administered, approximately 200 mL are added (circuit-line primed). Furthermore, in case of thickened ventricular septum,

one extra minute is added. Del Nido CPL has been recently introduced in our centre and it is generally delivered cold, at 4°C.<sup>11</sup> The amount of CPL administered is dosed as 20 mL/kg, with a maximum of 1000 mL in patients that weights more than 50 kg. Whenever patients weigh less than 50 kg or have a relatively low starting hematocrit value, the benefits of using Del Nido CPL may be offset by the adverse effects of hemodilution.

## Conclusions

In our centre, up to a year ago, the dominant type of CPL solution utilized was Bretschneider CPL, accounting for more than 90% of cases. In this last year, an increase in the use of Del Nido CPL has been reported, and cases, to date, account for approximately 80%. This new CPL delivery system allows for maintenance of the same pump set-up and same CPL circuit reducing the risk of accidents.

These risks can be related to the incorrect assembly of the circuit, but the presence of the colored clamps and the pre-intervention evaluation of the checklist allows the perfusionist to avoid perfusion accidents, especially during emergencies. Furthermore, avoiding tampering with the preset setting of the pumps, it determines a standardization which is the basic principle for avoiding errors while conducting extracorporeal circulation.

In all centres that use different CPL strategies, the ReverseTWO CPL circuit is a valid system, based on colour-coding tubing and clamps. It is easily primed and

prepared, extremely easy to use and greatly reducing storage costs.

### Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

### Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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