Cardiopulmonary Bypass in a Fledgling Center for Open Heart Surgery

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Original Article

ABSTRACT

Background: Cardiopulmonary bypass (CPB) allows the patient's heart and lungs to be temporarily devoid of circulation, with respiratory and cardiac activity suspended so that intricate cardiac, vascular, or thoracic surgery can be performed in a safe and controlled environment. Perfusion practice in Nigeria is a relatively new emerging field owing to the slow development of cardiac surgery programs in the country. It is therefore necessary to document and establish scientific, evidence-based protocols that are unique to our environment.

Objectives: To describe the management of patients on CPB (without the use of a cardioplaegia heat exchanger) at our hospital.

Patients and Methods: This was a cross-sectional study from a prospectively collected clinical database of patients operated at our hospital for intra-cardiac defects utilizing cardiopulmonary bypass over a period of 2 years between 2015 and 2017.

Results: A total of nine (9) patients who were operated on for intra-cardiac defects at UITH between the years 2015 and 2017, were placed on CPB. Oxygenated blood was added to the cardioplaegia solution in a ratio of two parts crystalloid to one part fully oxygenated patient whole blood (obtained from the bypass circuit). No cardiolplaegia heat exchanger and delivery system was used for these surgeries. We employed continuous conventional ultrafiltration during CPB. Surgeries were done under mild to moderate hypothermia. There were 8 long-term survivors with one mortality.

Conclusion: We conclude that cardiopulmonary bypass can be safely conducted in a resource challenged facility with some modifications to the conventional technique.

Key Words: Activated clotting time, cardioplaegia, cardiopulmonary bypass, cross-clamp time, extracorporeal circulation, oxygenator.

Received: 2 March 2024**, Accepted:** 21 October 2024

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ISSN: 2090-925X, The Egyptian Journal of Cardiothoracic Anesthesia 2024, Vol.18, No 2

INTRODUCTION

John Gibbon is credited with developing the first mechanical cardiopulmonary bypass (CPB) system in 1953[1]. Despite rapid advancement and increased variation in extracorporeal technology, the basic concepts remain essentially the same **(Figure 1**).

Cardiac surgical procedures are considered high-risk operations with estimated postoperative in-hospital mortality rates of 3-6% for all combined cardiac surgical procedures[2,3] and even higher mortality rates in high-risk populations[4]. Intraoperative factors such as CPB duration may significantly alter the risk of in-hospital mortality[5].

DOI: 10.21608/ejca.2024.274051.1001

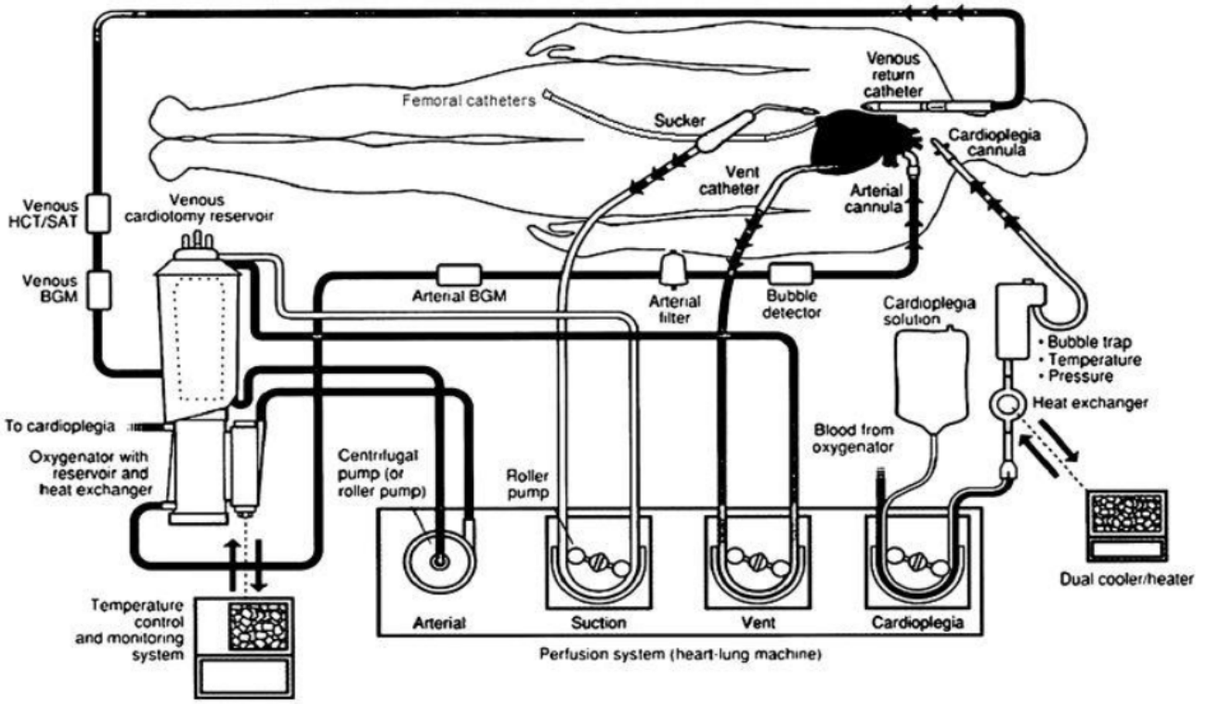

Figure 1: Typical configuration of a basic CPB circuit. BGM = blood gas monitor; SAT =oxygen saturation[9].

Professor Udekwu and his team with the aid of members of the International College of Surgeons were responsible for the first successful use of cardiopulmonary bypass in Nigeria[6]. About the same time, Dr Grillo and his group of cardiothoracic professionals (all Nigerians) at the University College Hospital (UCH), Ibadan performed a series of open-heart surgeries. Since then, the number of open-heart surgeries done in Nigeria has gradually risen[7]. The open-heart surgery team at our hospital, led by the first author, pioneered the series of open-heart procedures at this facility using the limited resources available[8]. The aim of this study is to describe the management of patients placed on CPB (without the use of a cardioplaegia heat exchanger) at our hospital.

PATIENTS, MATERIALS AND METHODS

Institutional settings

This is a cross-sectional study from a prospectively collected clinical database of 9 patients who were operated at our hospital for intra-cardiac defects using cardiopulmonary bypass over a period of 2 years between 2015 and 2017.

The hospital is a tertiary health care center located in Kwara State, north-central region of Nigeria. In addition to referrals from within the state, it also receives from neighbouring states of Kogi, Niger, Ekiti, Osun, and Oyo, and occasionally from beyond.

Cardiopulmonary bypass equipment

The heart-lung machine used was Century Baxter, PDS Medical solutions, USA. Oxygenators used were thymus paediatric oxygenators by Nipro, Brazil. Nipro paediatric custom tubing circuit (which comes with a pre-bypass filter) and arterial line filter (ALF) were used for the bypass circuit. Arterial blood gas monitoring was accomplished with the iSTAT machine from Abbott laboratory, USA using the CG8 cartridge. Activated clotting time (ACT) monitoring was accomplished with the Haemocron response ACT analyzer by Werfen USA LLC. Monitoring devices include pressure sensors and alarm, low level sensor and alarm and air emboli protection system (these were integral components of the heart-lung machine).

Cardiopulmonary bypass procedure

Priming solution

Ringer's lactate solution with addition of 25% albumin or gelofusin as colloid was the priming solution (**Table 1**).

Table 1:. Properties of Ringer's Lactate :

Sodium (mEq/L)	130
Potassium (mEq/L)	4
Magnesium (mEq/L)	0
Chloride (mEq/L)	109
Acetate (mEqwL)	0
Gluconate (mEq/L)	0
Phosphate (mEq/L)	0
Lactate (mEq/L)	28
Calcium (mEq/L)	1.5-3.0
Calculated osmolarity (mOsm/L)	273
pH range	6.0-7.5

Three thousand IU of heparin was added to the priming solution in all cases prior to recirculation. Other priming additives used are listed in (**Table 2**).

Table 2: Bypass circuit prime constituents:

500 ml Ringer's lactate base solution to which the following are added:
25% Albumin 5-7 ml/kg or gelofusin 15 ml/kg
20% Mannitol 2 ml/kg
8.4% sodium bicarbonate 5 ml/kg
Blood (if HCT < 45%)
Blood (if HCT < 45%)
Sodium Heparin 3000 IU start

Cardioplaegia

Electromechanical quiescence was achieved using a customised cardioplaegia formulation[9] Matindale St. Thomas's cardioplaegia concentrate mixed with other constituents was used (**Table 3**).

Table 3: Cardioplaegia constituents:

600ml Ringer's lactate base solution to which the following are added:
St Thomas CP concentrate, 40ml
25% dextrose, 10ml
2% Lidocaine, 5ml
50% Magnesium sulphate, 2ml
8.4% Sodium bicarbonate, 50ml
20% Mannitol, 50ml
Oxygenated blood, 350ml

This Cardioplaegia provides up to ninety minutes cardiac arrest.

Our base solution for cardioplaegia was Ringer's lactate (properties listed in **Table 4**).

Table 4: Apollo Children's Hospital circuit constituents :

Priming fluid	Cardioplaegia
Plasmalyte A + 0.9% Normal saline	Sterofundin
20% Mannitol (2ml/kg)	KCl
7.5% NaHCO3 (2ml/kg)	Calcium
20% Albumin(5ml/kg)	Mannitol
6% Hydroxyethylstarch (10ml/kg)	Lidocaine
Blood (if necessary)	Blood

No cardiolplaegia heat exchanger and delivery system was used for any of the surgeries however the lines were primed and a bubble isolator on the pressure monitoring line helped to trap any bubble that may have inadvertently found its way into the delivery circuit. The crystalloid components of the cardioplaegia were premixed in an empty sterile intravenous fluid bag with dual infusion ports. One of the ports, the outlet port was connected to the cardioplaegia pump (the cardioplaegia pump line has an integral temperature probe to monitor the temperature of cardioplaegia delivered). This serves as the cardioplaegia delivery line. The second port was connected to the oxygenator. This line was used to add oxygenated blood to the cardioplaegia solution. The volume of blood added was measured by the drop in blood volume from the venous reservoir.

The cardioplaegia additives to this base solution are listed in (Table 3). This formulation served as the crystalloid component, which was mixed with blood in a ratio of two parts crystalloid to one part fully oxygenated patient whole blood (obtained from the bypass circuit immediately at the beginning of bypass). The blood-crystalloid cardioplaegia was thoroughly mixed together and placed in an ice slush to cool. The limitation to this simple delivery method is the inability to deliver cardioplaegia at 40 C. The delivery temperature with this simple method was within 10-120 C. With the aid of a male-female extension line, Cardioplaegia was delivered to the aortic root at a dose of 20 ml/kg body weight at 70-80 mmHg aortic root pressure. The root pressure was measured by connecting one end of a male-male pressure line to a 3-way stopcock attached to the aortic root cannula and the other end to a pressure transducer connected to the multiparameter monitor. Delivery was by single dose antegrade route using 12 Fr aortic root cannula with ¼" side vent port.

Cannulation and monitoring

Aortic cannulation was by a straight tip cannula, venous cannulation was via both the superior and inferior vena cavae with curved, metal-tip, right-angled cannulae. At the initiation of bypass, 250 mg stat of solumedrol (**Figure 2**) (methyl prednisolone with sodium succinate) was administered.

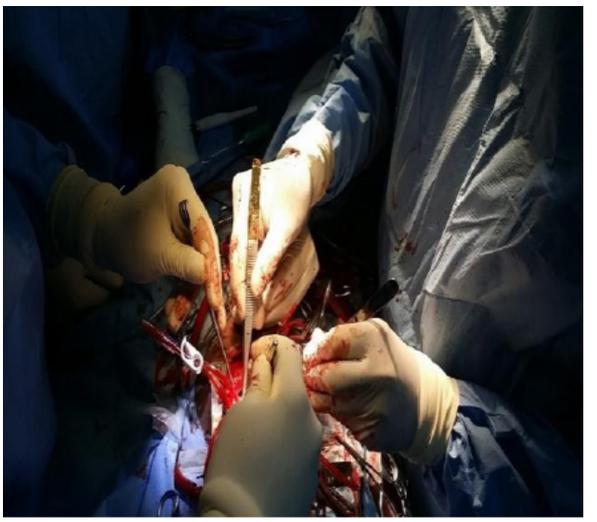

Fig.2: Patient under CPB in UITH as seen from the operating field. (Notice the tubings and cannulae)

Arterial blood gas (ABG) was checked every 15 minutes during bypass and appropriate correction made when necessary. Activated clotting time (ACT) was checked every 30 minutes and heparin added if it went below 480 seconds. The average ACT on bypass was 501 seconds. Nadir haematocrit (HCT) was maintained at 30% throughout the procedures. Mean systemic blood pressure ranged between 30-50 mmHg during bypass, with the average being 40 mmHg.

We employed continuous conventional ultrafiltration during the bypass time. Surgeries were done under mild to moderate hypothermia. Patients were cooled to 320 C for ASDs and VSDs and 250 C for TOF.

Rewarming and post-bypass period

During rewarming and shortly before the release of cross-clamp, 1.0ml/kg mannitol and 1.0ml/kg sodium bicarbonate (8.4%) were delivered.

The remaining circuit volume post bypass was either haemoconcentrated and given directly to the patient via the aortic cannula or was collected in a blood bag and handed over to the anaesthesiologist for subsequent transfusion. Patients' electrocardiogram (ECG) resumed to sinus rhythm following rewarming and removal of cross-clamp with two of the patients needing defibrillation.

Data collection and analysis

The clinical folders of all patients who had open-heart surgeries from 2015 to 2017 were retrieved from the records department of the hospital. The information obtained from these records included demographic data such as age, sex, weight and height; preoperative diagnosis and surgical pathology, the cardiac bypass equipment employed, total bypass time, cross-clamp time, priming and cardioplegia solutions used and the surgical outcome. All data was analyzed using SPSS version 20. Summary data is presented as mean ± standard deviation or percentages as appropriate.

RESULTS

Demographic data

Patient age varied between 2 and 15years with mean age of 5.33years (3.87). The male:female ratio was 6:3. The patients; weights ranged from 7.5-42kg with a mean of 17.8kg (S.D. 9.9).

Surgical pathology

They include 2 atrial septal defects (ASD), 5 ventricular septal defects (VSD), 1 tetralogy of Fallot (TOF) and 1 supravalvular pulmonary stenosis (PS) from Noonan's syndrome.

outcome

All patients were extubated within 24 hours of surgery with good vital signs. There was minimal or no evidence of pulmonary oedema or respiratory compromise and no evidence of renal insufficiency. No seizure or evidence of brain damage was recorded. One of the patients was reoperated a week post ASD repair as a result of cardiac tamponade from pericardial effusion. She subsequently had a subxiphoid tube pericardiostomy.

Of the nine patients, one (11%) died. This was a 4 year-old female who had a patch closure of VSD with PDA ligation. The patient died about five hours after surgery secondary to a low cardiac output state from complete heart block. The summary of the outcome of all the patients are presented in (**Table 5**).

Table 5: Nine cases of open heart surgical procedure performed in UITH, Ilorin :

S/NO	PATHOLOGY	PROCEDURE	AGE(Yrs)/ SEX	Weight(kg), BSA (m2)	OUTCOME
1	Large atrial septal defect, Pericardial effusion developed few days after open heart surgery	Pericardial patch closure of ASD, subxiphoid tube pericardiostomy	15/F	42.0, 1.41	Long Term Survival
2	Ostium secundum atrial septal defect	Pericardial patch closure of ASD with pulmonary valvotomy	7/F	17.9, 0.77	Long Term Survival
3	Ventricular septal defect with persistent ductus arteriosus	Patch closure of VSD with RVOT resection and PDA ligation	5/M	20.0, 0.82	Long Term Survival
4	Ventricular septal defect	Patch closure of VSD	4/M	17.0, 0.71	Long Term Survival
5	Ventricular spetal defect	Patch closure of VSD	3/M	10.0, 0.51	Long Term Survival
6	Ventricular septal defect with persistent ductus arteriosus	Patch closure of VSD with PDA ligation	4/F	13.2, 0.59	Died in ICU from cardiac arrhythmia
7	Supravalvular pulmonary stenosis from Noonan's syndrome	Open pulmonary valvotomy with supra-annular patching	4/M	15.6, 0.67	Long Term Survival
8	Ventricular septal defect and atrial septal defect from Down's syndrome	Patch closure of VSD and ASD	4/M	17.2, 0.72	Long Term Survival
9	Tetralogy of Fallot	Patch closure of VSD with RVOT resection	2/M	7.5, 0.44	Long Term Survival

Cross-clamp time (CXT) varied between 32 and 75 minutes with a median 65minutes. Total bypass time was between 59 and 163 minutes with median of 100 minutes. The average post-operative haematocrit was 35%.

DISCUSSION

Extracoporeal circulation (ECC) has allowed astonishing progress in cardiac surgerypermitting surgeons to stop the heart and safely carry out reparative procedures (**Figure 1, 3A**). The goal of CPB is to guarantee an accurate metabolic support during cardiac surgery procedures in maximum safety. Ignazio identified the macro-areas related to time as safety, practice, understanding, interpretation, and management during extracorporeal circulation[10].

These cardiac surgeries were done in collaboration with the paediatric cardiac surgery team from Apollo Hospitals, Chennai (**Figure 3B**).

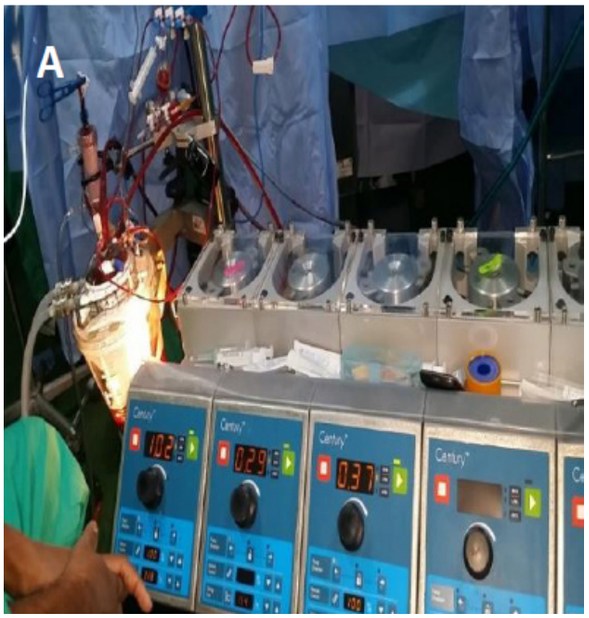

Figure 3: Heart-Lung machine in operation at UITH **(A)**

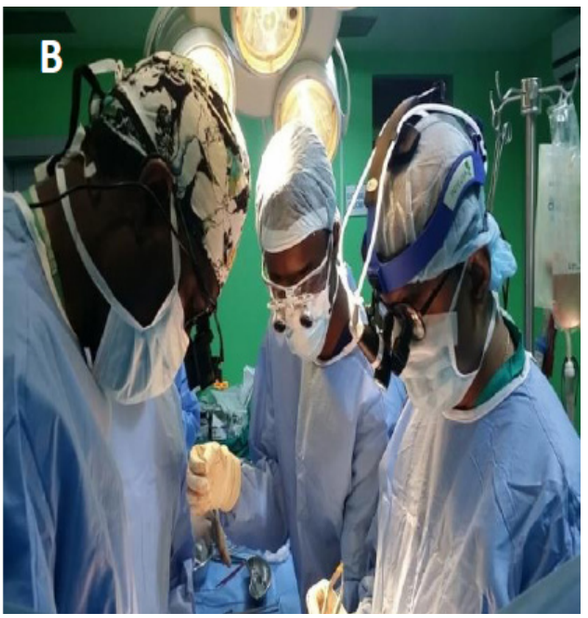

Figure 3: Surgeons operating on a patient's heart at UITH **(B).**

Some of the protocols employed were adapted from the Apollo Children's Hospital perfusion protocol which has been in use for many years. The priming fluid constituent and the cardioplaegia formulation from the Apollo Children's Hospital, Chennai, are listed in table 4.

Albumin was used as a colloidal agent in the priming solution to maintain the oncotic pressure and this also serve to coat the bypass circuit and oxygenator, preventing contact activation of the compliment system. Theoretically, an albumin coating may preserve platelet function and increase functional oxygenator life by helping to prevent "capillary leak" within a microporous membrane oxygenator[11].

Our priming base solution, Ringer's lactate, is a slightly acidic solution (table 1) therefore we added sodium bicarbonate to the prime to buffer this acidity and prevent systemic acidosis while a steroid (solumedrol) was given on bypass to attenuate the inflammatory response to bypass[12].

Our lowest haematocrit (HCT) of 30% on bypass is in line with most paediatric perfusion protocols across the world. Asli and Okan proposed that HCT of 30% should be targeted for mild to moderate hypothermia[13]. Children and especially infants, present a special problem with regards to haemodilution as most paediatric CPB circuits have a minimum priming volume of 700 to 800mls. There is a theoretical decrease in microcirculatory flow with HCTs above 30%. Loor et al estimated the nadir HCT to be at 30% (25th to 75th percentile, 27% - 33%)[14] Lower nadir HCT was associated with higher maximum intraoperative lactic acid, worse renal function, more myocardial injury, longer post-operative ventilator support, longer hospital stay and higher mortality[14].

Haemofiltration was necessary to wash away metabolites and compliment factors activated during the bypass period and also serves to remove excess fluid caused by the haemodilution from the prime. This results in therapeutic haemoconcetration leading to a satisfactory post-operative haematocrit.

The arterial line pressure was taken at a point just distal to the arterial line filter (ALF). This allowed us to monitor the pressure of blood going into the ascending aorta. We however did not have a pre-arterial filter pressure monitor which we did not consider essential.

We did not use a cardioplaegia delivery system with integral heat exchanger because the device to achieve this was not readily available in the country at the time and the fact that it also significantly raises the cost of the surgery[15] which our patient population could also not afford.

Decreasing the myocardial metabolic rate with hypothermia is a common practice for cardioplaegia delivery. Hypothermia decreases oxygen and high-energy phosphate consumption while providing its own additional cardioplaegic effect at low temperatures.

We added magnesium to our cardioplaegia because of its potential benefit. The calcium influx associated with myocardial contraction, if allowed to accumulate, may disrupt relaxation causing a diastolic stiffness with poor myocardial recovery. Magnesium has been shown to be a natural calcium channel blocker which may be how it improves ventricular recovery when added to hypothermic cardioplaegia solutions.

Aerobic metabolism is not usually possible for the entire myocardial arrest period. Therefore, anaerobic glycolysis must be supported. Our cardioplaegia mix incorporates sodium bicarbonate as a buffering solution to

scavenge excess hydrogen ions and assist in maintaining intracellular pH.

Some centers use only crystalloid cardioplaegia; we have added the patient's blood to our cardioplaegia mix because red blood cells (RBCs) contain a high concentration of carbonic anhydrase, an enzyme that facilitates the scavenging of hydrogen ion with bicarbonate ion to generate carbon dioxide and water. This property of the RBCs may in fact be its most important role in cardioplaegia[16]. Other roles include supporting anaerobic glycolysis in the myocardium and acting as an energy substrate for metabolism. It should also be noted that our cardioplaegia is more of crystalloid than blood with a resultant decrease in the blood viscosity. This aids in the perfusion of the microvascular bed, especially the subendothelial capillaries and may contribute to the relatively longer arrest period we have with our solution.

Shortly before the release of the aortic cross-clamp, we delivered sodium bicarbonate and mannitol to act as buffer and hyperosmolar agent. Myocardial oedema and ischaemia significantly contribute to reperfusion injury. We believe the addition of these agents to the circuit helped to mitigate this process.

In Nigeria, cardiac surgery practice has being limited by a number of factors which include: funding, cost, expertise, institutional will, and suitability of patients[15,17]. The estimated cost of open-heart surgery is $12,945 - 39,474 in Belgium[18], $25,499- 165,168 in the United States of America[19] and $6,230 - 11,200 in Nigeria[20]. In our center, our patients were billed between $4,500 to $5,000.00 for ASDs and VSDs. This appears to be about $1,200 to $1,700 less than the average cost of the surgeries in the country at the time. We were able to reduce the cost by the brand of consumables we selected and the non-usage of cardioplaegia delivery heat exchanger. The perfusion consumables used were also custom-made and were different from the set up that was sold in the country at that time.

CONCLUSION

We conclude that open heart surgery can be safely conducted in a resource challenged facility in a safe and effective manner when an appropriate protocol for cardiopulmonary bypass is utilized.

ACKNOWLEDGEMENTS

The authors acknowledge the support and collaboration by the team from Apollo Children Hospitals, Chennai, India lead by Dr. Neville Solomon in the conduct of the procedures.

CONFLICTS OF INTEREST

There are no conflicts of interest.

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