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Relation between right ventricular function and the time of extubation after total repair of tetralogy of fallot in the pediatirc population

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ABSTRACT

Objective(s): To study the relation between the systolic and diastolic right ventricular (RV) function in relation to the time of extubation after total repair of tetralogy of Fallot (TOF) in a pediatric population.
Design: Prospective, descriptive, non-randomized study.
Setting: Pediatric cardiac surgery unit at Ain Shams University Hospitals, Cairo, Egypt. The study was conducted from January 2016 to February 2018.
Participants: A total of 60 patients having elective primary total repairs of TOF made up the study sample. The patients were divided into two groups based on the time of extubation: Group I included patients who were extubated 6 hours or more after the procedure, while Group II included patients who were extubated within the first 6 hours.
Interventions: Total corrective surgery involving open-heart surgery with cardiopulmonary bypass. Measurements and Main Results: Early outcomes of mortality and morbidity were evaluated. RV systolic and diastolic functions were evaluated in the routine echocardiography performed on the first and fifth postoperative days. Additionally, patients' inotropic drug requirements during their intensive care unit (ICU) stays were calculated to produce the inotropic index for evaluation of postoperative low cardiac output. Group I contained 32 patients, while Group II contained 28. The mean ages in Group I and II, respectively, were 1.2 ± 0.8 years and 1.5 ± 0.9 years (p = 0.180). The mean weight in Group I and II, respectively, was 10.5 ± 2.5 kg and 9.86 ± 3.2 kg (p = 0.396). There were 20 (62.5%) males in Group I and 18 (64.29%) males in Group II (p = 0.886). Mortality was 2 cases (6.3%) in Group I and 1 case (3.6%) in Group II, with no statistical difference. Postoperative echocardiographic examination revealed significantly better RV functional parameters in Group II than in Group I.

1. Introduction

Reducing costs and managing resources efficiently while maintaining optimal patient care and comfort has become the new challenge in the field of pediatric cardiac surgery, where the trend is toward the concept of doing more with less . Finding the balance between economic restraint and patient safety is a critical question in the design of new procedures and therapeutic protocols. Fast-tracking cardiac surgery patients so that they are extubated within 6 hours is becoming an established practice in recently published series. The practice of ultrafast-tracking has also recently emerged, with patients being extubated in operating rooms or within the first 2 hours from discharge to the Intensive care unit.[1]

The benefits of fast-tracking cardiac surgical patients include more rapid recuperation (as this practice shortens the period of critical care); the psychological boost it gives to patients and their relatives; and reduced stress on ICU staff and the health care system. The practice of fast-tracking also reduces costs, as it reduces requirements for sedatives and inotrope and reduces cardiac complications.

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These results are due, in part, to fewer ventilator-associated complications. Fast-tracking requires coordination between the personnel involved in providing care to these patients. The role of the cardiothoracic surgeon involves proper patient selection and achieving optimal surgical correction with speed and precision while minimizing aortic cross-clamping time and cardiopulmonary bypass (CPB) time; adequate hemostasis is a crucial factor in this technique. The role of the cardiac anesthesiologist involves proper and meticulous choice and titration of drugs, fine-tuning hemodynamics, adequate invasive monitoring, and efficient pain relief. The perfusionist should provide smooth conduct of the CPB with adequate myocardial protection and sustained normothermia. The rest of the team will be providing smooth transitions between different stages of surgery and error-free delivery of patient care.[2]

The aim of this study is to explore postoperative right ventricular (RV) function – both systolic and diastolic – in tetralogy patients in relation to the time of extubation.

2. Materials and Methods

After obtaining approval of the ethics committee and parental consent, we conducted a prospective, randomized study of a sample of 6 0 consecutive pediatric patients aged (6 months to 3 years) undergoing total repair of tetralogy of Fallot (TOF) between January 2016 and February 2018 at Ain Shams University Hospitals and affiliated hospitals in Cairo, Egypt.

Patients were divided based on the timing of the extubation following corrective surgery for TOF into:

Group I: Patients extubated 6 hours or more after discharge to ICU.

Group II: Patients extubated in the operating room or within 6 hours of discharge to ICU.

We included patients with suitable anatomy (McGoon $>$ 1.8) and pulmonary annulus score $>$ -3. McGoon's ratio is calculated by dividing the sum of the diameters of RPA (at the level of crossing the lateral margin of vertebral column on angiogram) and LPA (just proximal to its upper lobe branch), divided by the diameter of aorta at the level above the diaphragm [DRPA /DDTAO)+(DLPA / DDTAO)]. An average value of 2.1 was noted in normal subjects. Ratio above 1.2 is associated with acceptable postoperative RV systolic pressure in Tetralogy of Fallot. Ratio below 0.8 is deemed inadequate for complete repair of PA – VSD while z score table is used for pulmonary annulys scoring.

We excluded neonates and patients with small pulmonary arteries (Mc-Goon $\leq$ 1.8), pulmonary annulus score $\leq$ -3, or CPB $\geq$ 2.5 hours. Redo and emergency surgeries were also excluded. Patients having other associated pathologies, such as atrioventricular septal defects (AVSD), were excluded, as were patients with failed caudal blocks.

3. Technical considerations

3.1. Anesthetic protocol

The main factors taken into consideration regarding anesthetic technique for our cohort of patients were the anesthetic agents and narcotics dose, hemodynamic stability, and analgesia. Patients were premedicated with 0.3 mg/kg midazolam oral route 30–50 minutes before induction of the procedure. We used Mask induction with sevoflurane (2-6%). Fentanyl (1–10 mcg/kg) with muscle relaxant atracurium (0.5 mg/kg) was also given at induction. Maintenance was with low dose inhalational anesthesia sevoflurane and low dose fentanyl at 1–2 mcg/kg boluses . Muscle relaxant atracurium was maintained during the procedure at 0. 1 mg /kg every 20 min.

Custodiol cardioplegia with histidine-tryptophan–ketoglutarate (HTK–Custodiol; Koehler Chemi, Alsbach-Hähnlein, Germany) was used as the sole agent for myocardial protection. It was given as a single dose of 30–50 ml/kg over 6–8 minutes to provide myocardial protection during the whole procedure.

Patients were evaluated after coming off bypass, and, in the absence of severe pulmonary dysfunction by transesophageal echocardiography (TEE), hemodynamic instability, excessive bleeding, and concerns regarding the airway, the neuromuscular blockade was reversed and they were allowed to regain consciousness. Patients were extubated once they showed adequate ventilatory effort and satisfactory gas exchange, as evaluated by the capnography reading and analysis of blood gases and train of four for neuromuscular recovery. The extubation was performed either immediately in the operating room by the senior anesthesiologist or within 2 hours of discharge to the ICU by the pediatric intensivist.

Patients' hemodynamics and vital signs were meticulously monitored to ensure early detection of any signs of low cardiac output or compromised ventilatory parameters. Fentanyl at (0.1 mcg/kg/hour) in incremental doses or meperidine (pethidine®) at 0.5–1 mg/kg intramuscular, along with acetaminophen (120mg) / diclofenac (75mg) suppositories, was used as needed for postoperative pain control.[3]

3.2. Caudal anesthesia

The patients were positioned for the blind caudal epidural block. A line was drawn to connect the bilateral posterior superior iliac crests and used as one side of an equilateral triangle to approximate the location of the sacral hiatus. After palpating the sacral cornua as two bony prominences, the sacral hiatus could be identified as a dimple in between. An A22-gauge needle was inserted into the caudal space through the sacrococcygeal ligament using an aseptic technique. If no blood or Cerebro-Spinal Fluid CSF was aspirated, a 1 ml/kg dose of 0.25% bupivacaine

(Marcaine®) was given. After 20 min of the block and the commencement of skin incision, an increase in heart rate of above 20% was considered a sign of a failed block and the patient was excluded.[4]

3.3. Echocardiographic considerations

Two-dimensional echocardiography, including Doppler color flow imaging and pulsed/continuous-wave Doppler studies, was performed on the first and fifth postoperative days. Detailed echocardiography was performed with a focus on Doppler indices of (RV) function.

The following measurements were used to evaluate RV function:

3.4. Tricuspid inflow and myocardial velocities

These parameters were used to assess the RV diastolic function. Diastole occurs in different phases and segments in the right ventricle. Thus, multiple parameters are required to estimate the diastolic function. Doppler flow evaluation of the right atrium, tricuspid valve inflow, lateral tricuspid valve annulus, hepatic veins, and Inferior Vena Cava (IVC) size and collapsibility are required to assess the RV diastolic function adequately . The effects of inspiration on inflow velocities are neutralized by obtaining the Doppler signals in multiple beats.

3.4.1. E/A ratio and tricuspid valve E-wave deceleration time

We began the assessment of the tricuspid inflow velocity profile by placing Doppler sampling in the apical four-chamber view at the tip of the tricuspid valve. Velocities of the E and A waves were measured, and the E/A ratio was calculated. Figure 1

In normal diastolic function, the early filling velocity E is higher than the atrial contraction velocity A. Reversed E/A ratio of less than 0.8 with increased E-wave deceleration time represents impaired RV relaxation. When the RV is restrictive to the filling, which is a late phase of diastolic dysfunction, there is an increased E/A ratio (> 2.1) associated with decreased deceleration time (< 120 ms).[5]

3.4.2. Isovolumetric relaxation time (IVRT)

Diastolic indexes included myocardial early (E′) and atrial peak velocities (A′) (m/sec), E′/A′ ratio, and isovolumetric relaxation time (msec) (IVRT was defined as the time interval between the end of S and the onset of E′). The myocardial contraction and relaxation times are evaluated using tissue Doppler imaging in the apical four-chamber view with ECG gating.[6]

3.4.3. Myocardial performance index (MPI, Tei index)

The MPI is calculated as the ratio between the sum of the isovolumetric periods and the ejection time of the RV. A physiological parameter that depends more on functional criteria than structural features, it is a measure of the total RV function, representing both systolic and diastolic functions, and it correlates well with the radionucleotide-estimated RV ejection fraction.

A typical value for the MPI is 0.28 ± 0.04; it usually increases in diseases associated with RV dysfunction.[6]

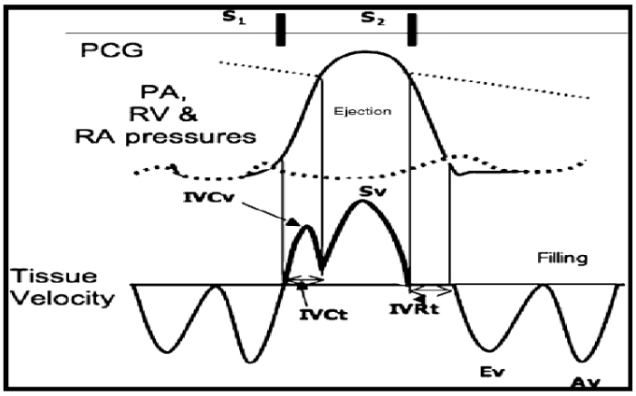

Fig. 1: Dopper wave analysis for measurements of RV function: (Anavekar et al. 2007 [8])

S1: First Heart Sound
S2: Second Heart Sound
PA: Pulmonary Artery, RA: Right Atrium, RV: Right Ventricle, S wave: Ejection Wave
IVRT: Isovolumetric Relaxation Time, IVCT: Isovolumetric Contraction Time
EV: Passive Relaxation Filling, AV: Atrial Relaxation Filling

3.4.4. Tricuspid annular plane systolic excursion (TAPSE)

The TAPSE is a measure of the RV systolic function. It is a two-dimensional measure obtained by placing the Doppler m mode sampling cursor through the lateral portion of the tricuspid valve annulus in the apical four-chamber view.[7–10]

3.4.5. Gradient across the RV outflow tract (RVOT)

The gradient across the right ventricular outflow tract was measured by continuous-wave Doppler echocardiography of the right ventricular outflow tract with sampling just below the pulmonary valve.[11]

3.4.6. Degree of pulmonary incompetence

The degree of pulmonary incompetence, classified as mild, moderate, or severe, was judged from Doppler color flow imaging of the RV outflow tract. A duration of regurgitation jet less than two-thirds of the diastole was considered mild to moderate. A duration of the regurgitation jet more than two-thirds of the diastole accompanied by flow reversal in the distal pulmonary artery was considered to represent severe pulmonary incompetence.[12]

Antegrade late diastolic flow in the right ventricular outflow tract (RVOT) was taken as a marker of restrictive RV physiology. The previous parameters were correlated to the type of surgery and clinical indices of RV dysfunction.[13]

The previous data were correlated with clinical indices of RV dysfunction such as evidence of right heart failure, chest tube drainage times, duration of inotropes, duration of ICU stay, dosage of diuretics, and central filling pressures.[13]

3.4.7. Calculation of vasoactive inotropic score (VIS)

The hourly doses of the following inotropic and vasoactive medications were recorded for the first 48 h following post-operative admission to the ICU: Dopamine, dobutamine, epinephrine, norepinephrine, milrinone, and vasopressin. In our study, the VIS was calculated as described by Wernovsky, and the formula was expanded to include other vasoactive agents commonly used to define a VIS. The maximum VIS level over the first 48 h was recorded.

The following formula was used:

VIS = Dopamine dose (μg/kg/min) + Dobutamine dose (μg/kg/min) + 100 $\times$ epinephrine dose (μg/kg/min) + 10 $\times$ Milrinone dose (μg/kg/min) + 10,000 $\times$ Vasopressin dose (U/kg/min) + 100 $\times$ Norepinephrine dose (μg/kg/min).[14]

3.5. Statistical data analysis

Patient data were coded as variables. Quantitative variables are expressed as the mean and standard deviation (SD). Qualitative variables are expressed as frequencies and percentages. Student's t-test and the Mann-Whitney test were used to compare continuous variables between the study groups. The chi-square test was used to examine the relationship between categorical variables. A p-value $<$ 0.05 was considered statistically significant. The collected data were reviewed using the Statistical Package for Social Science (IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp, 2011). The sample size was calculated with a confidence interval of 95% and an 8% margin of error.

4. Results

During the study period, 94 patients with TOF underwent surgery for total correction of the associated anomalies. Based on the inclusion/exclusion criteria, a sample of 60 consecutive patients operated upon for TOF during the period January 2016 to February 2018 was prospectively reviewed. They were divided into two groups:

Group I: Delayed extubation after 6 hours (32 patients)

Group II: Early extubation on the operating table or up to 2 hours after discharge to ICU (28 patients)

The patients were consecutive, and the allocation was based on the timing of extubation that was decided upon by the operating team. All patients were matched to the selection criteria before inclusion in the sample.

4.1. Preoperative parameters

Both groups were comparable for most of the parameters, with no statistically significant difference between the groups. The mean ages, in Groups I and II, respectively, were1.2 $\pm$ 0.8 years and 1.5 $\pm$ 0.9 years (p = 0.180). The mean weights were, respectively, 10.5 $\pm$ 2.5 kg and 9.86 $\pm$ 3.2 kg (p = 0.396). There were 20 males (62.5%) in Group I and 18 males (64.29%) in Group II (p = 0.886).

4.2. Pulmonary artery anatomy

Both groups were similar in RVOT anatomy and pulmonary artery anatomy. There was no statistically significant difference between the groups in the RVOT gradient, McGoon ratio, central pulmonary artery diameter, pulmonary artery valve annulus, or branch pulmonary artery diameters. The mean McGoon ratios in Groups I and II, respectively, were 2.1 $\pm$ 0.4 and 2.0 $\pm$ 0.5 (p = 0.4). The mean RVOT gradients were, respectively, 75.6 $\pm$ 25.6 mmHg and 80.2 $\pm$ 20.8mmHg (p = 0.446).

4.3. Operative details

The mean bypass times in Groups I and II, respectively, were 99.12 $\pm$ 19.37 min and 94.86 $\pm$ 21.69 min (p = 0.428), with no significant difference. Cross-clamp times were, respectively, 71.93 $\pm$ 15.11 min and 69.45 $\pm$ 19.08 min (p = 0.583), with no significant difference. More patients in Group II had valve-sparing procedures – 9 (32.14%) in comparison to 5 (15.63%) – although this difference was not statistically significant.

4.4. Echocardiographic analysis

Analysis the of echocardiographic parameters of RV function after corrective surgery for TOF revealed better values for both diastolic and systolic parameters in Group II than in Group I, both in day 1 and day 5 readings. Clinical parameters of RV function, namely the central venous pressure values, were also better in Group II than in Group I. Additionally, less inotropic drug support, as expressed by lower inotropic drug score values, was required in Group II than in Group I, with a statistically significant difference. Also, more patients in Group I (31.25%) had low cardiac output than in Group II (7.14%), a difference that was also statistically significant.

4.5. Postoperative parameters

The mortality was 2 cases (6.3%) in Group I and 1 case (3.6%) in Group II, with no statistically significant difference. All patients who died did so due to RV failure and low cardiac output.

The two groups were similar in most postoperative morbidities, but patients in Group II had shorter ICU stays and shorter total hospital stays, with a statistically

Table 1: Showing postoperative outcome I the two groups

Postoperative Data	GI: Delayed extubation	No=32	GII: Early extubation	No=28	P value
Mortality (No - %)	2	6.3%	1	3.6%	0.635
ICU stay (days) (Mean ± SD)	8.07	± 7.88	4.40	± 1.77	0.013
Hospital stay (days) (Mean ± SD)	12.49	± 8.47	8.45	± 2.15	0.012
Arrhythmia (JET) (No - %)	6.00	18.75%	2.00	7.14%	0.187
Heart block (No - %)	2.00	6.25%	1.00	3.57%	0.635
Reoperation (No - %)	4.00	12.5%	2.00	7.14%	0.490
Bleeding rate ml/first 24hrs (mean ± SD)	85.00	± 50.7	75.00	± 45	0.422
Renal failure (No - %)	3.00	9.375%	1.00	3.57%	0.369
Neurological manifestations (No - %)	4.00	12.5%	6.00	21.4%	0.355
Wound infection (No - %)	6.00	18.75%	3.00	10.71%	0.384
Sepsis (No - %)	3.00	9.375%	1.00	3.57%	0.369

$p < 0.05$ is significant
GI: Group I, GII: Group II
Data is presented in mean and standard deviation (SD) or as number (NO) with percentage %

significant difference. Table 1.

5. Discussion

The early tracheal extubation of children following congenital heart surgery is not a new concept, but it has received renewed attention with the evolution of 'fast-track' management for cardiac surgical patients. 'Early extubation' in most studies refers to extubation within the first 6 hours after surgery. 'Ultrafast extubation' refers to extubation in the operating room within the first two hours after surgery.[14]

Ventilation of patients after cardiac operations has been the standard practice for the past three decades. Initially, the practice was justified because of the high incidence of respiratory insufficiency and low cardiac output state after cardiac operations and the use of high-dose anesthesia techniques. This practice has been a driving force behind the fast-track cardiac anesthesia alternative. The potential benefits of early extubation include cost savings, reduced dependency on nursing, and reduced airway and lung trauma. This technique also improves cardiac output and renal perfusion with spontaneous respiration and reduced stress and discomfort associated with endotracheal suctioning and weaning from the ventilator.[15]

In our study, we successfully extubated 28 patients on the OR table after total correction of TOF. There were no significant differences in mortality between the two groups, and the rate of postoperative complications was comparable between the groups.

However, our study sample included patients with good pulmonary anatomy and isolated tetralogy lesions, a fact that must be considered before attempting to extubate more complex pulmonary anatomies or patients with associated lesions in addition to the classic tetrad seen in Fallot's patients.

Certain specific factors must be carefully considered in neonates and young infants, as these are essential arguments for delaying the extubation of these patients and thus prolonging the ICU stay:

1. More complicated surgical procedures to correct the cardiac anomalies, thus avoiding early initial palliation and staged repair.

2. Increased risk of compromised cardiorespiratory function in neonates and young infants in the immediate postoperative period due to limited physiological reserves and to the augmented stress response to the cardiopulmonary bypass circuit.

3. Initiation of a systemic inflammatory response syndrome (SIRS) due to the reaction of different blood components to various elements of the cardiopulmonary bypass circuit. This response is magnified in neonates and small infants due to their low blood volume in comparison to the large surface area of the bypass circuit. This inflammatory response leads to increased interstitial fluid and a generalized capillary leak. The total lung water may be increased, resulting in decreased lung compliance and reduced gas exchange. Myocardial edema may also result in impaired systolic and diastolic function. Renal dysfunction may ensue, and dialysis may be required. A drop in cardiac output of 20% to 30% is common in the first 24 hours following surgery. Delayed sternal closure may be required for myocardial edema.[16]

Halimić el at (2014) conducted a study of 100 congenital heart surgery patients who underwent open-heart surgery using cardiopulmonary bypass and concluded that early extubation could safely be attempted in most of the pathologies they studied, which included left to right shunt lesions without obstructions. The group do, however, mention that younger age and prolonged use of the cardiopulmonary bypass might be factors that argue against early extubation.[2]

Kolth et al., in 2002 conducted a study of 102 patients undergoing corrective open-heart surgery requiring bypass. They successfully extubated 88% of these patients in the OR and 12% on arrival in the ICU. No patients in the early extubation group required individual airway support, reintubation, or increased inotropic support after ICU admission.[17]

Even the early work of Barash et al., in 1980, emphasizes the safety and feasibility of early extubation of pediatric patients requiring open heart surgery for correction. In a study of 197 patients less than three years old, of whom 57% underwent a cardiopulmonary bypass for the repair, they report a 72% success rate in immediate extubation of these patients in the operating room.[18]

Our patients had proper surgical repairs with no residual gradient across the RVOT, well-closed ventricular septal defects (VSD)s, and meticulous hemostatic techniques. Fast-tracking the patients in our study involved a highly coordinated team activity. Healthcare personnel interacted through a harmonized program of management at different stages of patient treatment to ensure the rapid and smooth transition between therapeutic phases. Essential concepts of our fast -track program included a selection of short-acting an esthetic drugs, normothermia, standardized surgical techniques, early extubation, strict patient temperature control, early ambulation, and, finally, adequate pain control. All these factors complement one another to shorten the hospital stay, leading to early discharge.[19]

Our study also revealed better RV function in patients having early extubation in comparison to patients having delayed extubation. Considering that the groups had similar pulmonary anatomy and nearly identical surgical techniques and myocardial preservation strategies, the effect of early extubation is highlighted as the primary factor contributing to this difference.

These findings might be explained by understanding the physiological changes in RV function following total repair of patients with TOF. Interrupting the pulmonary annulus during the repair of TOF results in loss of function of the pulmonary valve, with resultant pulmonary regurgitation (PR). Postoperative PR results in RV volume overload. The acute change from pressure overload to volume overload after total repair results in RV dysfunction with subsequent limited exercise capacity. Gradually, the RV dilates with subsequent changes in the electrical properties of the RV myocardium with resultant atrial and ventricular arrhythmias and may be sudden death. The changes in the RV myocardial properties begin in the early postoperative period. Early extubation limits the physiological changes induced by mechanical ventilation – most importantly, the increased pulmonary vascular resistance due to positive-pressure ventilation cycles – thus decreasing the degree of pulmonary regurgitation and improving pulmonary forward blood flow. Our results contradict the previous view that RV function is assisted by mechanical ventilation.[20,21]

Changes in lung volume alter autonomic tone and pulmonary vascular resistance and, at high lung volumes, compress the heart in the cardiac fossa in a manner similar to cardiac tamponade.

Thus, early extubation in the uncomplicated total repair of tetralogy may actually improve RV function due to the elimination of the detrimental effects of mechanical ventilation on cardiac function**.**

Our findings conform to those of Dodgen et al. (2013), who conducted a retrospective observational study of 164 patients with TOF with a median age of 200 days and a median weight of 6.8 kgs. This study demonstrates that early extubation is successful in most patients, with a low failure rate, and that the majority of extubation failures occur in the first 24 hours. Extubation in these patients was associated with improvement in the hemodynamic parameters, mainly arterial blood pressure and improvement of tachycardia, and improvement of ventilatory functions, with improvement in PaO2. Following early extubation there were also improvements in myocardial contractility and a decrease in the inotropic score in the early postoperative period.[22]

Previous studies have used mechanical ventilation with delayed extubation to support patients through the surgical repair of congenital heart disease. The use of mechanical ventilatory support after weaning from the cardiopulmonary bypass is not dissimilar from that used with other surgical procedures that do not involve CPB. In the early decades of congenital cardiac surgery under cardiopulmonary bypass, patients manifested critical pulmonary changes as a direct result of the activation of a proinflammatory cascade due to the artificial surface-blood interface. This exposure leads to massive complement activation and release of mediators, leading to a generalized capillary leak and significant pulmonary dysfunction. Recent developments in biomaterials and CPB technology, and the routine use of ultrafiltration that results in the removal of mediators, have improved the response of the pediatric population to the cardiopulmonary bypass interface. Thus, in most cases, pulmonary function after bypass weaning can be compatible with spontaneous ventilation. This fact supports the recent trend toward early extubation, with patients being separated successfully from mechanical ventilation shortly after completion of the procedure.[23] Thus, with the advances in cardiopulmonary bypass, the role of mechanical ventilation is limited to cardiopulmonary support secondary to the changes induced by the surgical repairs; it has less involvement in supporting the patient's physiology against stress responses to the cardiopulmonary bypass and imprudent multi-inflammatory reactions.[24,25]

The concept of on-table extubation is an intriguing current topic, and the suggested benefits of shorter hospital stays and earlier ambulation are attractive in an era in which the development of surgical techniques and operating equipment is guided by their degree of invasiveness. The apparent benefits of decreasing the non-physiological effects of positive-pressure ventilation on RV function are demonstrated in our study by improvements in the overall RV function.[26]

The beneficial effects of early extubation are explained by analysis of the effects of positive-pressure ventilation on RV preload, afterload, and contractility.

Preload of the right ventricle relates to the volume of the venous return. The blood flows passively from the systemic venous blood pool to the right atrium. This blood pool depends on multiple factors: the circulating blood volume, the vasomotor tone, and the blood sequestration in various peripheral circulation networks. The venous return relates directly to the gradient between the great extrathoracic veins and the right atrium. Spontaneous inspiration increases this gradient, thus increasing venous return. As such, RV preload and stroke volume increase during spontaneous breathing (or during negative-pressure mechanical ventilation). With spontaneous inspiration, the intrathoracic pressure decreases and the pressure gradient increases with resultant increase in venous return. Venous return is a major determinant of cardiac stroke volume and cardiac output. The opposite process occurs during positive-pressure ventilation. The pressure gradient decreases, with a subsequent decrease in right atrial filling and RV filling. Thus, stroke volume decreases and cardiac output drops.[27]

The RV after load can be defined as the systolic wall stress of the right ventricle. The wall stress relates directly to the pulmonary vascular resistance (PVR). The pulmonary resistance is affected by changes in the lung volume and arteriolar tone. The pulmonary vasculature is divided into alveolar and extra-alveolar blood vessels. The alveolar vessels are small vessels that run into the alveolar septum and thus are subjected to the intra-alveolar pressure as well as the surrounding pressure. Thus, the resistance in these vessels relates to mechanical changes in and the vasomotor tone of the vessels. Two mechanical states of the lung cause elevation of the PVR. The first state is low lung volume post expiration. The extra-alveolar vessels become tortuous, underfilled, and thus mostly collapsed. The alveolar pressure decreases, and thus there is a local state of hypoxia in the intra-alveolar space, which will in effect cause an increase in the local vasomotor tone. The second state is maximal lung inflation post inspiration. The intra-alveolar pressure increases, and the vessels are stretched and compressed by the alveolar overdistension. This last condition occurs with positive-pressure ventilation and positive end expiratory pressure (PEEP) with high tidal volumes. The elevated PVR increases the RV overload and thus decreases the cardiac output.[28–35]

With positive-pressure ventilation, the airway pressure will compress the surface-running coronary vessels, resulting in decreased coronary-myocardial perfusion and depressed function during this type of ventilation.[36,37]

6. Limitations

The small sample size and restricted study design limits the generalizability of our findings about the beneficial effects of early extubation on RV function. Our cohort included patients with TOF who had good anatomy and who underwent adequate surgical repairs with no residual lesions. Strict management of all aspects of the operative setup was designed to exclude these factors from confounding the measurement of postoperative RV function. Further studies on larger samples of patients and including those with more complex anatomies will be required to expand the evidence for or against early extubation.

7. Conclusion

Analysis of RV function, including parameters of both systolic and diastolic function, reveals better results in the early extubation group. This improvement might be related to the removal of the adverse effects of positive-pressure ventilation on RV function and on the heart in general. Careful decision-making regarding early extubation of patients is needed, since positive -pressure ventilation may be necessary and helpful to support ventilation in patients with compromised pulmonary reserves or cardiac function after surgical correction and cardiopulmonary bypass stress. Nevertheless, early extubation after pediatric cardiothoracic operations can be safely achieved in a designated group of patients with good dynamics following repair and with strict control of the cardiopulmonary bypass reactions through coordinated anesthetic and perfusion techniques. Specific parameters demonstrating maintained cardiopulmonary mechanisms after corrective cardiac surgery are required to ensure success and maintenance of early extubation.

8. Source of funding

None.

9. Conflict of interest

None.

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