Measures to Improve In-Hospital Outcomes of Patients Undergoing Surgical Repair for Anomalous Origin of Left Coronary Artery from Pulmonary Artery

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ABSTRACT

Background: Anomalous origin of the left coronary artery from the pulmonary artery (ALCAPA) is a rare congenital anomaly leading to progressive left ventricular dysfunction and mitral regurgitation. We conducted this study to investigate various measures to optimize the outcomes of surgical correction for ALCAPA.

Materials And Methods: This was a single-centre, retrospective, observational study including consecutive patients operated for ALCAPA. The main outcomes evaluated were in-hospital mortality, duration of mechanical ventilation, and duration of intensive care unit (ICU) stay. Independent sample t-test and Fisher’s exact test were used for the analysis of continuous and categorical variables respectively.

Results: 31 patients underwent surgical correction for ALCAPA during the study duration. The median age was 7.3 months with a range of 21 days to 25 months. All patients underwent coronary re-implantation with the coronary button transfer technique. There was no in-hospital mortality, the mean duration of mechanical ventilation and ICU stay was 117.6 hours and 10.7 days respectively. Age at admission, development of acute kidney injury after surgery, lactate levels at 12- and 24-hours post-surgery, and heart rate at ICU admission and 12-hours post-surgery were significantly associated with mechanical ventilation duration longer than 48 hours. Use of a combination of levosimendan and milrinone and elective intermittent nasal continuous positive airway pressure ventilation after extubation in all patients with severe left ventricular dysfunction were helpful in preventing low cardiac output and need for reintubation post-surgery respectively.

Conclusion: Surgical correction for ALCAPA by coronary re-implantation has an excellent short-term outcome. Optimal postoperative management is of utmost importance for achieving the best results.

Keywords: ALCAPA, coronary reimplantation, levosimendan, milrinone, nasal continuous positive airway pressure ventilation

INTRODUCTION

Anomalous origin of the left coronary artery from the pulmonary artery (ALCAPA) is an uncommon congenital anomaly with an incidence of around 1 in every 3,00,000 live births accounting for 0.25 to 0.5% of all congenital heart defects. This anomaly is well-tolerated in utero, as the pulmonary artery carries oxygenated blood at systemic pressures, and hence, adequate left coronary
perfusion is maintained throughout. However, after birth, the circulation dynamics change with a fall in pulmonary artery pressure due to a progressive decrease in pulmonary vascular resistance and predominantly de-oxygenated blood flowing through pulmonary arteries. This in turn leads to hypoperfusion and hypoxia of the left ventricle resulting in progressive left ventricular dysfunction and mitral regurgitation.\[6\]

Clinical presentation is common during infancy after 8 weeks\[8\] with features of Congestive heart failure (CHF) like tachypnoea, sweating, and failure to thrive. Without prompt surgical intervention, mortality rates are close to 90% at one year,\[9\] although survival till adulthood has been reported.\[10\] Early surgical repair is the definitive treatment modality\[11\] with the goal of achieving two coronary artery circulation. Surgical techniques for achieving this goal include coronary artery reimplantation, Takeuchi repair (creation of aortopulmonary window with tunnelling of aorta to left coronary ostium)\[12\] and coronary artery bypass grafting.\[13\] In the present study, we report the outcomes of ALCAPA correction and various measures which are helpful in improving the outcomes.

**MATERIALS AND METHODS**

**Study design:** This was a retrospective observational study including consecutive patients of ALCAPA who had undergone surgical correction between January 2014 to December 2019 at our institute. Ethical approval for the study was given by the Institute ethics committee. Case files of all eligible patients were retrieved from the medical records section of the institute. All relevant variables like demographic details, clinical and diagnostic data, and peri-operative details were recorded. Operative notes were used for extracting surgical details. The main outcomes studied were in-hospital mortality, duration of mechanical ventilation, and duration of intensive care unit (ICU) stay. Variables associated with these outcomes were analyzed.

**Definitions**

Acute kidney injury (AKI): It was defined as a rise in serum creatinine by $\geq 0.3$ mg/dl within 48 hours or an increase in serum creatinine $\geq 1.5$ times above the baseline or urine output $<0.5$ ml/kg/hours for 6 hours.\[9\]

Severe left ventricular dysfunction was defined as an ejection fraction of $\leq 30\%$, moderate as $30\%$-$40\%$, and mild as $40\%$-$50\%$ by 2-D echocardiography.\[9\]

Mitral regurgitation was graded as mild, moderate, and severe as per the standard echocardiographic criteria recommended by ACC/AHA.\[11\]

Postoperative sepsis: It was defined as the presence of positive blood cultures.

**Surgical technique**

All patients were preoperatively evaluated and screened for any infection, and if found were treated accordingly for the same. Anesthesia protocol during surgery consisted of induction with ketamine, glycopyrrolate, fentanyl, and vecuronium followed by maintenance with a high dose of fentanyl with vecuronium and sevoflurane. Injection cefuroxime at a dose of $30$ mg/kg was administered during induction and repeated after coming off-pump.

Uniform Cardiopulmonary bypass (CPB) protocol was followed in all patients. Cardiopulmonary bypass was performed using a Quadrox 10,000 (Maquet, Rastatt, Germany) for neonates, infants, and pediatric patients up to 10 kg. For neonates and infants, the flow was maintained to get a cardiac index of up to $3.2$ L/m$^2$/min, and for pediatric patients, the flow was maintained to achieve a cardiac index of up to $2.8$ L/m$^2$/min. Before bypass, 400 units/kg of heparin was systemically administered to achieve optimal anticoagulation.

CPB was established via aortic and bi-caval cannulation, with two cardioplegia cannulas in the aorta and pulmonary artery, respectively. Moderate hypothermia was utilized during surgery. Del Nido cardioplegia was used in all patients. Branch pulmonary arteries were looped and snuggled during cardioplegia delivery. All patients underwent coronary reimplantation via the coronary button transfer technique. The left coronary button was harvested from the main pulmonary artery and implanted into ascending aorta at its posterolateral aspect (nearly 7 o’clock position), while the gap in the pulmonary artery was closed with autologous treated pericardium. Mitral valve repair was done in those with severe mitral regurgitation. Conventional and Modified ultrafiltration was used during and after CPB, respectively. Patients with preoperative severe left ventricular dysfunction were given a bolus dose of milrinone (50 $\mu$g/kg) while rearming on the pump at 34-degree centigrade and maintenance dose of milrinone (0.5 $\mu$g/kg/min), levosimendan (0.1 $\mu$g/kg/min) and adrenaline (0.08 $\mu$g/kg/min) were started while weaning off CPB. Those with preoperative mild to moderate left ventricular dysfunction were weaned from CPB using a combination of milrinone and adrenaline with the same doses as mentioned above.

**Postoperative care**

All patients were kept in the ICU and ventilated for at least 24 hours after surgery. Additional vasopressors (vasopressin...
at 0.0003 units/kg/min, noradrenaline at 0.04 µg/kg/min) were added and titrated to maintain adequate hemodynamics. Patients who had significant tachycardia at ICU admission were administered magnesium sulfate (50 mg/kg/dose) 12 hourly for three days.

A negative fluid balance (25 to 50 ml/kg over 24 hours) was maintained throughout the intensive care unit stay using injectable diuretic infusion (Furosemide at 2 mg/kg/day) in patients with normal renal function. Peritoneal dialysis was done in patients with altered serum creatinine and urine output less than 0.5 ml/kg/hr. Depending upon the hemodynamic status of patients, weaning and extubation were considered from the first postoperative day. Trial of extubation was given based on clinical parameters and arterial blood gas analysis. We used elective intermittent non-invasive continuous positive airway pressure ventilation after extubation in patients with preoperative severe LV dysfunction. Angiotensin-converting enzyme inhibitor was started after extubation in all patients without contraindications for the same.

Intravenous antibiotics (cefuroxime) were stopped after three doses in the postoperative period in patients with the uncomplicated course. Patients who had chest open post-surgery were given injection piperacillin-tazobactam which was continued till 24-hours after chest closure. Blood cultures were done 48-hours post-surgery and repeated subsequently if platelet counts had a decreasing trend from the baseline, or there were other signs of sepsis.

Statistical analysis
Statistical analysis was done using “IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.”. Quantitative variables were expressed as mean ± standard deviation while qualitative were expressed as percentages. Independent sample t-test was used for comparison of means between groups while Fisher’s exact test was used for comparison of categorical variables. A “p” value of less than 0.05 was taken as significant.

RESULTS

Baseline characteristics [Table 1]
31 patients underwent surgical correction for ALCAPA during the study duration. The male-female sex ratio was almost equal. The mean age at admission was 7.3 months with the youngest and oldest patients being 21 days and 25 months old, respectively. Congestive heart failure (24 patients, 77%) and failure to thrive (28 patients, 90%) were the most common presenting symptoms. 13 patients (42%) had lower respiratory tract infections at the time of presentation and were treated for the same before undergoing surgical correction. Although most of the patients (26, 83.8%) had severe left ventricular dysfunction, severe mitral regurgitation was seen in only 13% of the patients. No other cardiac anomaly was seen in any of the patients included in the study.

Intra-operative variables [Table 1]
All patients underwent surgical re-implantation of the left coronary artery to the aorta via coronary button transfer. The mean cardiopulmonary bypass time was 94 minutes with a mean aortic cross-clamp time of 69 minutes. Four patients (12.9%) having concomitant severe mitral regurgitation, underwent mitral valve repair along with coronary reimplantation. All patients were weaned of cardio-pulmonary bypass in the operating room, and none required Extracorporeal membrane oxygenation (ECMO). Seven patients (22.5%) had chest open post-surgery due to hemostasis issues, which was subsequently closed on post-op day one.

Postoperative variables [Table 2]
All patients with severe preoperative left ventricular dysfunction received levosimendan (26, 83.8%) for initial 48 hours. Adrenaline (31, 100%) and milrinone (31, 100%) were administered to all patients in the initial 48 hours. Levosimendan was stopped after 48 hours, and other inotropes were continued till deemed necessary by the hemodynamic status of patients. Noradrenaline was required in fourteen patients (45.2%) and Vasopressin was required in only one patient (3.2%).

Post-surgery, severe left ventricular dysfunction persisted in all the patients (26, 83.8%) with preoperative severe

| Variables                        | Mean ± SD/Number (percentage) |
|----------------------------------|-------------------------------|
| Age (months)                     | 7.3 ± 6                       |
| Males                            | 16 (51.6%)                    |
| Weight (kg)                      | 5.1 ± 1.7                     |
| CHF                              | 24 (77.4%)                    |
| Failure to thrive                | 28 (90.3%)                    |
| Lower respiratory tract infection| 13 (41.9%)                    |
| Severe LV dysfunction            | 26 (83.8%)                    |
| MOD LV dysfunction               | 3 (9.6%)                      |
| Mild LV dysfunction              | 2 (6.4%)                      |
| Severe MR                        | 4 (12.9%)                     |
| Moderate MR                      | 8 (20.8%)                     |
| Mild/Trivial MR                  | 19 (61.3%)                    |
| Cardio-pulmonary bypass time     | 93.9 ± 16.5                   |
| Aortic cross-clamp time          | 69.1 ± 13.5                   |
| Chest open (post-op day zero)    | 7 (22.6%)                     |
| Mitral valve repair              | 4 (12.9%)                     |

Quantitative data are presented as mean ± standard deviation and qualitative as number (percentage). Units as indicated; CHF: Congestive heart failure; LV: Left ventricle; MR: Mitral regurgitation.
dysfunction. However, mitral regurgitation regressed in most of the patients after surgery. Of four patients with severe mitral regurgitation who underwent mitral valve repair, three had residual mild regurgitation, and one had moderate regurgitation.

Postoperative sepsis, as defined by positive blood cultures, occurred in 6 patients (19.3%), and was managed with appropriate antibiotics guided by culture sensitivity. Endotracheal tube aspirate culture was positive in 7 patients (22.3%), however, it was not associated with any radiological evidence of ventilator-associated pneumonia and hence was not treated. Acute kidney injury (AKI) complicated the course in 8 patients (25.8%) and was managed with peritoneal dialysis. Renal function subsequently recovered to normal in all patients who had developed acute kidney injury. Two patients developed diaphragmatic palsy in the postoperative period and underwent diaphragm plication for the same.

Outcomes [Table 3]

There was no in-hospital mortality and all patients were discharged in stable condition. The mean duration of mechanical ventilation was 117.6 hours with a range of 24 to 408 hours. 21 Patients (67.7%) required mechanical ventilation for longer than 48 hours while remaining required mechanical ventilation for less than or equal to 48 hours. Mean ICU stay and hospital stay durations were 10.7 and 16.2 days, respectively [Table 2].

Multiple variables were assessed for association with the duration of mechanical ventilation. Age at admission was significantly associated with the duration of mechanical ventilation longer than 48 hours. The mean age of those requiring mechanical ventilation for more than 48 hours was 5.8 months as compared to 10.5 months in those requiring mechanical ventilation for less than 48 hours. Heart rates at ICU admission and 12 hours post-admission was significantly higher in patients requiring mechanical ventilation for longer than 48 hours. Serum lactate levels at 12- and 24-hours post-surgery and development of acute kidney injury were also significantly higher in patients requiring mechanical ventilation for more than 48 hours. None of the other variables evaluated were significantly associated with prolonged duration of mechanical ventilation [Table 3].

DISCUSSION

This single-center retrospective study from a tertiary care hospital showed that surgical correction for ALCAPA by reimplantation of the left coronary artery to aorta has a very good short-term outcome with negligible mortality and morbidity.

The median age of patients in our study (5.5 months) is almost like that reported in various other studies.[13,14] This suggests that the majority of patients become symptomatic at a very early age and require early surgical intervention. Even if asymptomatic, surgery should be performed as soon as the diagnosis is established to prevent deterioration of left ventricular function. Our study as well studies by Cabrera et al.[14] and Lange et al.[15] show that surgical correction is feasible and successful in neonates also. Equal sex ratio seen in our study is a finding consistently seen in other large studies[16] also.

Most of the patients in our study were symptomatic with either CHF, failure to thrive, or both. Studies by Isomatsu et al.[17] and other studies[18] have also shown similar findings. Early development of symptoms is beneficial in a way that it leads to early diagnosis and management. The reason behind the high percentage of symptomatic patients in our study is the presence of severe left ventricular dysfunction in the majority of patients. A study by Zhang HL et al.[19] showed that patients with left ventricular ejection fraction less than 50% presented at a much younger age as compared to those with a left ventricular ejection fraction of more than 50%. Severe mitral regurgitation was seen in a few patients only, the probable reason being relatively early presentation and diagnosis of ALCAPA before the development of excessive LV dilatation and adverse remodeling seen in adults.[20]

All patients in our study underwent coronary reimplantation (coronary button transfer) to achieve...
a two coronary artery system. Of multiple described techniques for ALCAPA repair, coronary reimplantation seems to be the one with the best long-term results. So, other surgical techniques should be considered only when coronary reimplantation is not feasible, i.e., as in the case of left coronary arising from non-facing pulmonary sinus. Cardiopulmonary bypass and cross-clamp times were much lower in our study as compared to those reported by Dehaki et al. and Zhang et al. while being like those reported by Kazmierczak PA et al. and Lange et al. The differences could be explained by variations in surgical techniques, the experience of the surgeon, and institutional protocols.

Concomitant mitral valve repair was done only in a small number of patients with severe regurgitation. Moderate mitral regurgitation was not addressed as the degree of regurgitation generally improves with the restoration of coronary blood supply and subsequent reverse remodeling of the left ventricle and papillary muscles. In fact, very few patients require mitral repair at index surgery and the repair can be done at a later date in those with persistent severe regurgitation.

None of the patients in our study required circulatory support in form of Extra-corporeal membrane oxygenation (ECMO) or left ventricle assist devices in the postoperative period. Mechanical circulatory support devices can be extremely useful in cases with persistent congestive heart failure, low cardiac output, or intractable arrhythmias after surgical correction. The non-requirement of circulatory support devices in our study can be explained by the fact that most of the patients were operated on as soon as feasible and were very young, with probably preserved myocardial viability leading to the recovery of contractile function after surgery. Patients with very severe left ventricular dysfunction and markedly dilated left ventricle and poor myocardial viability may be potential candidates for circulatory support devices in the postoperative period.

### Table 3: Association of variables with duration of mechanical ventilation

| Variables                        | Mechanical Ventilation duration | Mechanical Ventilation duration |
|----------------------------------|---------------------------------|---------------------------------|
|                                  | 48 hrs. (n = 10)                | >48 hrs. (n = 21)               |
| Age (months)                     | 10.5 ± 6.2                      | 5.8 ± 4                         | 0.038 |
| Males                            | 5 (50%)                         | 11 (52.4%)                      | 1 (ns) |
| Weight (kgs)                     | 5.53 ± 1.52                     | 4.85 ± 1.76                     | 0.28 (ns) |
| Sepsis                           | 0 (0%)                          | 6 (28.6%)                       | 0.14 (ns) |
| Preoperative Severe LV dysfunction | 7 (70%)                        | 19 (90.4%)                      | 0.29 (ns) |
| Acute kidney injury              | 0 (0%)                          | 8 (38.1%)                       | 0.032 |
| Chest open                       | 1 (1%)                          | 6 (28.6%)                       | 0.38 (ns) |
| Mitral valve repair              | 2 (2%)                          | 2 (9.5%)                        | 0.58 (ns) |
| CPB Time (min)                   | 94.38 ± 18.11                   | 93.61 ± 15.80                   | 0.90 (ns) |
| Cross clamp time (min)           | 71.76 ± 15.42                   | 70 ± 12.87                      | 0.73 (ns) |
| Lactate at ICU admission (mmol/litre) | 2.10 ± 0.78                    | 2.77 ± 0.90                     | 0.054 (ns) |
| Lactate at 12 hrs (mmol/litre)   | 1.85 ± 0.48                     | 2.62 ± 1.14                     | 0.04 |
| Lactate at 24 hrs (mmol/litre)   | 1.63 ± 0.34                     | 2.09 ± 0.56                     | 0.024 |
| Heart rate admission (beats/min) | 146.38 ± 14.65                  | 162.38 ± 14.91                  | 0.006 |
| Heart rate 12 hrs (beats/min)    | 144.38 ± 14.66                  | 159 ± 15.23                     | 0.01 |
| Heart rate 24 hrs (beats/min)    | 148.23 ± 17.53                  | 160.66 ± 19.01                  | 0.07 (ns) |
| CVP admission (cm)               | 7 ± 3.74                        | 7.72 ± 2.86                     | 0.55 (ns) |
| CVP 12 hrs (cm)                  | 7.38 ± 2.14                     | 7.61 ± 1.97                     | 0.76 (ns) |
| CVP 24 hrs (cm)                  | 7.69 ± 2.86                     | 8.33 ± 1.94                     | 0.46 (ns) |
| Adrenaline at admission (microgram/kg/min) | 0.11 ± 0.13                 | 0.10 ± 0.09                     | 0.70 (ns) |
| Adrenaline at 48 hrs (microgram/kg/min) | 0.16 ± 0.21                | 0.07 ± 0.07                     | 0.52 (ns) |
| Noradrenaline at 48 hrs (microgram/kg/min) | 0.09 ± 0.04                   | 0.09 ± 0.07                     | 0.94 (ns) |
| Milrinone at admission (microgram/kg/min) | 0.51 ± 0.03                  | 0.50 ± 0.12                     | 0.91 (ns) |
| Milrinone at 48 hrs (microgram/kg/min) | 0.49 ± 0.08                  | 0.47 ± 0.19                     | 0.79 (ns) |

Quantitative data are presented as mean ± standard deviation and qualitative as number (percentage). Significant variables are highlighted in bold. Units as indicated; CPB: Cardio-pulmonary bypass; CVP: Central venous pressure; ICU: Intensive Care Unit; ns: Not significant.
Our study didn't show significant improvement in left ventricular function in the early postoperative period. This was an expected finding as hibernating myocardium of the left ventricle recovers gradually over a period, despite restoration of blood supply. A study by Schwartz et al.\[27\] showed that left ventricular function recovers in almost all patients after an average duration of 2-7 months after surgical correction for ALCAPA.

The zero mortality rate seen in our study reflects the evolution of surgical techniques and improvement in perioperative management. This has been a worldwide trend with surgical mortality rates of ALCAPA repair declining sharply over the past four decades.\[28\] The mortality rate in a large study from India\[13\] in which coronary reimplantation technique was used exclusively was 9.6%, while several other large studies from different parts of the world have reported mortality rates ranging from 0 to 17%.\[16,22,28\] The variations in mortality rates across studies can be explained by differences in sample size, patient profiles, surgical techniques, and postoperative management protocols. According to us, the use of elective intermittent nasal CPAP and a combination of levosimendan and milrinone in patients with severe left ventricular dysfunction helped improve postoperative outcomes. Post-extubation intermittent nasal CPAP improves lung compliance and reduces Left ventricular afterload decreasing chances of reintubation.\[29\] Levosimendan and milrinone, both Ionodilators, may have contributed to improved outcomes, although, conclusive evidence for the same is lacking and further studies are required to unequivocally establish their utility.

The mean duration of mechanical ventilation and hospital stay in our study were similar to that reported by Cabrera et al.,\[14\] however, the duration of ICU stay in this study was slightly longer. This can be attributed to a relatively higher incidence of sepsis and acute kidney injury seen in our study. As seen in our study, younger age has been found to be associated with a longer duration of mechanical ventilation.\[16\] Expectedly, the development of acute kidney injury in the postoperative period led to the prolongation of mechanical ventilation duration.\[30\] Postoperative sepsis, although not significantly associated, was numerically higher in patients with prolonged duration of mechanical ventilation.

Interestingly, we found heart rate and lactate levels in the postoperative period to be significantly associated with prolonged mechanical ventilation. As per our knowledge, this is a novel finding and hasn't been reported previously. The plausible explanations for these findings can be a more severe hemodynamic perturbation and exaggerated inflammatory response to cardio-pulmonary bypass in these patients. Although the amount of ionotropic support can partially explain these findings we didn't find any significant differences in the type, dose, number, and duration of inotropic support between the two groups. Hence, a higher heart rate and lactate levels at 12 and 24-hours post-surgery can act as predictors for the need for prolonged mechanical ventilation.

**Limitations**

The biggest limitation of our study was the lack of follow-up data and, hence information on long-term outcomes of the patients was incomplete. However, several other studies that have looked into long-term outcomes of such patients show that the outcome is quite good with a low rate of reintervention, especially with coronary reimplantation technique.\[25,31,32\] The second limitation was the retrospective nature of the study with its inherent biases and a small sample size, which may have impacted the results. Also, being a single-center study with surgeries being conducted by highly experienced pediatric cardiac surgeons, the results may not be generalizable.

**CONCLUSION**

Early surgical correction of ALCAPA with coronary reimplantation, establishing two coronary artery circulation—in experienced hands is associated with excellent short-term and probably long-term outcomes. The use of the combination of levosimendan and milrinone and elective intermittent nasal CPAP may improve outcomes in patients with severe preoperative left ventricular dysfunction and needs to be studied further.

**Financial support and sponsorship**

Nil.

**Conflicts of interest**

There are no conflicts of interest.

**REFERENCES**

1. Al Umairi RS, Al Kindi F, Al Busaidi F. Anomalous origin of the left coronary artery from the pulmonary artery: The role of multislice computed tomography (MSCT). Oman Med J 2016;31:387-9.
2. Keith JD. The anomalous origin of the left coronary artery from the pulmonary artery. Br Heart J 1959;21:149-61.
3. Lardhi AA. Anomalous origin of left coronary artery from pulmonary artery: A rare cause of myocardial infarction in children. J Fam Community Med 2010;17:113-6.
4. Peña E, Nguyen ET, Merchant N, Dennie C. ALCAPA syndrome: Not just a pediatric disease. RadioGraphics 2009;29:553-65.
5. Wesselhoeft H, Fawcett JS, Johnson Arnold L. Anomalous origin of the left coronary artery from the pulmonary trunk. Circulation 1968;38:403-25.
6. Yau JM, Singh R, Halpern EJ, Fischman D. Anomalous origin of the left coronary artery from the pulmonary artery in adults: A comprehensive review of 151 adult cases and a new diagnosis in a 53-year-old woman. Clin Cardiol 2011;34:204-10.

7. Takeuchi S, Imamura H, Katsumoto K, Hayashi J, Katohgi T, Youz R, et al. New surgical method for repair of anomalous left coronary artery from pulmonary artery. J Thorac Cardiovasc Surg 1979;78:7-11.

8. Li D, Zhu Z, Zheng X, Wang Y, Wang Y, Xu R, et al. Surgical treatment of anomalous left coronary artery from pulmonary artery in an adult. Coron Artery Dis 2015;26:723-5.

9. Makris K, Spanou L. Acute kidney injury: Definition, pathophysiology and clinical phenotypes. Clin Biochem Rev 2016;37:85-98.

10. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: An update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr 2015;28:1-39.e14.

11. Otto CM, Nishimura RA, Bonow RO, Carabello BA, Erwin III JP, Gentile F, et al. 2020 ACC/AHA Guideline for the management of patients with valvular heart disease: A report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. J Am Coll Cardiol 2020;77:e25–197.

12. Surti J, Jain I, Shah K, Mishra A, Kandre Y, Garg P, et al. Predictive efficacy of procalcitonin, platelets, and white blood cells for sepsis in pediatric patients undergoing cardiac surgeries who are admitted to intensive care units: Single-center experience. Ann Pediatr Cardiol 2018;11:137-42.

13. Muzaffar T, Ahmad Ganie F, Gposal Swamy S, Wani N. The surgical outcome of anomalous origin of the left coronary artery from the pulmonary artery. Cardiov Res J 2014;8:57-60.

14. Cabrera AG, Chen DW, Pignatelli RH, Khan MS, Jeeva A, Mery CM, et al. Outcomes of anomalous left coronary artery from pulmonary artery repair: Beyond normal function. Ann Thorac Surg 2015;99:1342-7.

15. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: An update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr 2015;28:1-39.e14.

16. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: An update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr 2015;28:1-39.e14.

17. Takeuchi S, Imamura H, Katsumoto K, Hayashi J, Katohgi T, Youz R, et al. New surgical method for repair of anomalous left coronary artery from pulmonary artery. J Thorac Cardiovasc Surg 1979;78:7-11.

18. Zhang C, Zhang Z, Ding Y, Wang S, Pang C, Li Y. [Anomalous origin of the left coronary artery from the pulmonary artery in infants: Clinical features and the perioperative treatment strategies]. Zhonghua Er Ke Za Zhi Chin J Pediatr 2014;52:777-82.

19. Zhang H-L, Li S-J, Wang X, Yan J, Hua Z-D. Preoperative evaluation and midterm outcomes after the surgical correction of anomalous origin of the left coronary artery from the pulmonary artery in 50 infants and children. Chin Med J (Engl) 2017;130:2816-22.

20. Kubota H, Endo H, Ishii H, Tsuchiya H, Inaba Y, Terakawa K, et al. Adult ALCAPA: From histological picture to clinical features. J Cardiothorac Surg 2020;15:14.

21. Neumann A, Saikroups S, Bohyle D, Meschenmoser L, Breymann T, Westhoff-Bleck M, et al. Long-term results after repair of anomalous origin of left coronary artery from the pulmonary artery: Takeuchi repair versus coronary transfer. Eur J Cardiothorac Surg 2017;51:308-15.

22. Kazmierczak PA, Ostrowska K, Dryzek P, Moll J, Moll JJ. Repair of anomalous origin of the left coronary artery from the pulmonary artery in infants. Interact Cardiovasc Thorac Surg 2013;16:797-801.

23. Brown JW, Ruzmetov M, Parent J, Rodefeld MD, Torrente MW. Does the degree of preoperative mitral regurgitation predict survival or the need for mitral valve repair or replacement in patients with anomalous origin of the left coronary artery from the pulmonary artery? J Thorac Cardiovasc Surg 2008;136:743-8.

24. Ben Ali W, Metton O, Roubertie F, Pouard P, Sidi D, Raïsky O, et al. Anomalous origin of the left coronary artery from the pulmonary artery: Late results with special attention to the mitral valve. Eur J Cardiothorac Surg 2009;36:244-8; discussion 248-9.

25. Dodge-Khatami A, Mavroadis C, Bucker CL. Anomalous origin of the left coronary artery from the pulmonary artery: Collective review of surgical therapy. Ann Thorac Surg 2002;74:946-55.

26. Nasser BA, Alexi-Meschishvili V, Nordmeyer S, Weng YG, Börtecher W, Hübler M, et al. Predictors for the use of left ventricular assist devices in infants with anomalous left coronary artery from the pulmonary artery. Ann Thorac Surg 2010;90:580-7.

27. Schwartz MI, Jonas RA, Colan SD. Anomalous origin of left coronary artery from pulmonary artery: Recovery of left ventricular function after dual coronary repair. J Am Coll Cardiol 1997;30:547-53.

28. Lagones I, Kreutzer C, Romaní MI, Schlichter AJ. Outcomes after surgical correction of anomalous origin of the left coronary artery from the pulmonary artery. Rev Argent Cardiol 2010;78:6.

29. Gandhi H, Mishra A, Thosani R, Acharya H, Shah R, Surti J, et al. Elective nasal continuous positive airway pressure to support respiration after prolonged ventilation in infants after congenital cardiac surgery. Ann Pediatr Cardiol 2017;10:26.

30. Singh SP. Acute kidney injury after pediatric cardiac surgery. Ann Card Anaesth. 2016;19:306-13.

31. Fidulu DP, Dorohantu DM, Sharabiani MTA, Angelini GD, Caputo P, Parry AJ, et al. Outcomes following repair of anomalous coronary artery from the pulmonary artery in infants: Results from a procedure-based national database. Open Heart 2015;2:e000277.

32. Naimo PS, Fricke TA, d’Udekem Y, Cochrane AD, Bullock A, et al. New surgical method for repair of anomalous left coronary artery from pulmonary artery in infants: A comprehensive review of 151 adult cases and a new diagnosis in a 53-year-old woman. Clin Cardiol 2011;34:204-10.