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ORIGINAL ARTICLE / ÖZGÜN MAKALE

Predictors of extubation in the operating room after pediatric cardiac surgery: A single-center retrospective study

Pediatrik kalp cerrahisi sonrası ameliyathanede ekstübasyonun öngördürücüleri: Tek merkezli retrospektif çalışma

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ABSTRACT

Background: In this study, we aimed to evaluate the outcomes of our on-table extubation strategy in patients with congenital heart disease.

Methods: Between April 2021 and November 2022, a total of 114 pediatric patients (58 males, 56 females; median age: 25.3 months; range, 57.5 to 4.4 months) who were operated for congenital heart diseases were retrospectively analyzed. The patients were evaluated according to the Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery (STS-EACTS) scoring system. Perioperative patient data were analyzed and correlated with the extubation status.

Results: Overall, 56% of the patients were extubated in the operating room. There was an association between fluid balance per unit body surface area, longer cardiopulmonary bypass and cross-clamp times and on-table extubation. Lactate value prior to extubation, STS-EACTS mortality category, estimated mortality, and estimated morbidity were statistically significant with regards to the achievability of extubation. Multivariate analysis revealed lactate value prior to extubation and estimated postoperative length of hospital stay to be significant factors affecting on-table extubation. There was a significant correlation between decreased length of intensive care unit and hospital stay and on-table extubation.

Conclusion: The outcomes of our on-table extubation strategy for patients with congenital heart disease reveal the feasibility of this approach. Higher lactate and fluid balance/body surface area levels, longer cross-clamp and cardiopulmonary bypass durations, increased surgical complexity are indicators of a failure to perform on-table extubation. This strategy is also associated with shorter intensive care unit and hospital length of stays as an additional clinical benefit.

Keywords: Airway extubation, cardiac surgery, congenital heart diseases.

ÖZ

Amaç: Bu çalışmada doğumsal kalp hastalığı olan hastalarda ameliyathanede ekstübasyon stratejimizin sonuçları değerlendirildi.

Çalışma planı: Nisan 2021 - Kasım 2022 tarihleri arasında doğuştan kalp hastalığı nedeniyle ameliyat edilen toplam 114 pediatrik hasta 58 erkek, 56 kız; medyan yaş: 25.3 ay; dağılım, 57.5-4.4 ay) retrospektif olarak analiz edildi. Hastalar Göğüs Cerrahları Derneği-Avrupa Göğüs Kalp Damar Cerrahisi Derneği (STS-EACTS) skorlama sistemine göre değerlendirildi. Perioperatif hasta verileri analiz edildi ve ekstübasyon durumu ile ilişkilendirildi.

Bulgular: Genel olarak hastaların %56'sı ameliyathanede ekstübe edildi. Birim vücut yüzey alanı başına sıvı dengesi, uzamış kardiyopulmoner baypas ve kros-klemp süreleri ile ameliyathanede ekstübasyon arasında bir ilişki gözlemlendi. Ekstübasyon öncesi laktat değeri, STS-EACTS mortalite kategorisi, tahmini mortalite ve tahmini morbiditenin ekstübasyon edilebilirlik açısından istatistiksel olarak anlamlı olduğu bulundu. Çok değişkenli analizde ekstübasyon öncesi laktat değeri ve ameliyat sonrası tahmini hastanede kalış süresinin ameliyathanede ekstübasyonu etkileyen anlamlı faktörler olduğu belirlendi. Yoğun bakım ünitesinde ve hastanede yatış sürelerinin kısalması ile ameliyathanede ekstübasyon arasında anlamlı bir ilişki saptandı.

Sonuç: Doğumsal kalp cerrahisinde ameliyathanede ekstübasyon stratejimizin sonuçları, bu yaklaşımın uygulanabilirliğini ortaya koymaktadır. Daha yüksek laktat ve sıvı dengesi/vücut yüzey alanı seviyeleri, daha uzamış kros-klemp ve kardiyopulmoner baypas süreleri, artan cerrahi kompleksite, ameliyathanede ekstübasyonun gerçekleştirilememesine yönelik göstergeler olarak değerlendirilebilir. Ayrıca, bu strateji ilave klinik bir yarar olarak daha kısa yoğun bakım ünitesi ve hastanede kalış süresi ile ilişkilidir.

Anahtar sözcükler: Hava yolu ekstübasyonu, kalp cerrahisi, doğumsal kalp hastalıkları.

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The advances in the surgical and anesthetic techniques, as well as the perioperative care of the patients, has enabled the gradual improvement in the outcome expectations for the early-stage postoperative recovery of congenital heart disease (CHD) patients.[1-3] In this context, weaning of patients from mechanical ventilation constitutes an important factor in the course of the early postoperative period. Although postoperative mechanical ventilation in the intensive care unit (ICU) is still common practice in many institutions, early extubation including ultra-fast-track (UFT) extubation following surgery for CHD has been debated.[2-6]

In the literature, there are reports of the use of early extubation, including UFT extubation in a variety of congenital cardiac surgical procedures, but yet controversies revolve around the topic.[5,7,8] In this debate, benefits of the early extubation strategy were reported to reduce ventilator-associated complications, reduce the need for sedatives, and decrease the length of hospital stay.[1,3-7,9]

For the most part, congenital heart surgery patients can be extubated in the operating room.[1,4,6,8,10] While many factors have been mentioned in the literature for predicting the practicability of on-table extubation, no distinct fast-track protocol exist and extubation is carried out when a state of clinical well-being is agreed upon by the surgical and anesthesiologic team. In the present study, we aimed to identify the factors consisting of a patient status that is well enough for a consensus to be reached for extubation and the impact of this strategy on length of hospital stay. In this study, we present our experience with on-table extubation and postoperative course of congenital cardiac surgery patients.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Koç University Hospital, Department of Cardiovascular Diseases between April 2021 and November 2022. A total of 118 pediatric patients who underwent surgery were included. Patients who required extracorporeal membrane oxygenation support postoperatively (n=4) were excluded from the cohort to optimize the results of the outcome analysis for the length of hospital and ICU stays. Finally, 114 patients (58 males, 56 females; median age: 25.3 months; range, 57.5 to 4.4 months) were included. All patients were operated by the same surgical and anesthesiology team and preoperatively acknowledged to be candidates for on-table extubation. While this strategy was being implemented, the anesthesiology team was blinded to the use of the data in a future study. The pre-, intra-, and postoperative data of the patients until discharge were reviewed. The patients were evaluated according to the Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery (STS-EACTS) mortality and morbidity scoring systems.[11,12] Perioperative data, duration of need for ICU, and hospital stay were recorded. The patients extubated in the operating room were defined as Group 1 (n=64) and those extubated in the ICU were defined as Group 2 (n=50).

Prior to surgery, anesthesia was induced with propofol 2 mg/kg, fentanyl 1 to 2 μg/kg, rocuronium bromide 0.6 mg/kg and maintained with 0.8-1 MAC sevoflurane. Depth of anesthesia was monitored using bispectral index monitoring. Following the completion of the operation, surgical correction was confirmed by transesophageal echocardiography. The decision to proceed to extubation was based on a consensus reached by the surgeon, cardiologists, and anesthesiologists. For postoperative pain control, pre-extubation parasternal block was applied with 0.5 mL/kg of bupivacaine at 0.25% concentration. Following parasternal block, anesthesia was discontinued. To antagonize the effects of the muscle relaxant agents, 2 mg/kg of sugammadex was used. The following parameters were viewed as inclusion criteria for on-table extubation: sufficient spontaneous breathing; no evidence of pulmonary obstruction; stable hemodynamics with no evidence of relevant hemorrhage; body temperature ≥36°C; appropriate blood gas analysis according to pathology type with 40% fraction of inspired oxygen, and positive end-expiratory pressure of 5 cmH_2O. During the follow-up of the patients in the ICU, perfusions of 0.2 to 0.5 μg/kg/h of dexmedetomidine and analgesic doses of 0.5 to 1 μg/kg/h of fentanyl were initiated. As per routine protocol, 2 L/kg/min of non-invasive high-flow oxygen support was given to the patients postoperatively.

Statistical analysis

Statistical analysis was performed using the MedCalc Statistical software version 12.7.7 (MedCalc Software BVBA, Ostend, Belgium). The normality of continuous variables was analyzed using the Shapiro-Wilk test. Descriptive data were expressed in median and interquartile range (IQR) (Q3-Q1) for the non-normally distributed variables or number and frequency for normally distributed variables. Non-parametric statistical methods were utilized in the analysis of the values with skewed distribution. The Mann-Whitney U test was used to compare two non-normally distributed groups. The Pearson

chi-square and Yates continuity correction tests were used for categorical data comparison. For multivariate analysis, the multivariate logistic regression analysis was used. The relationship between on-table extubation and ICU and hospital stay were analyzed using the Spearman rank correlation. A two-sided *p* value of <0.05 was considered statistically significant.

RESULTS

The data pertaining to the operations and perioperative patient information are summarized in Tables 1 and 2. Two patient groups were homogenously distributed according to age, weight, and height. Between the two groups, there was a significant

Table 1. Table of operative data

Operation	Group 1 (On-table extubation)	Group 2 (ICU extubation)
Aortic valve repair	2	0
Aortic arcus reconstruction	1	1
Atrial septal defect	5	0
Atrial septal defect + pulmonary stenosis	1	1
Atrial septal defect + ventricular septal defect	6	3
Atrioventricular canal defect	0	4
Aortic coarctation + arcus repair	2	0
Central shunt	0	1
Double outlet right ventricle rerouting	2	1
Double outlet right ventricle re-routing + arcus repair	0	1
Ebstein anomaly	0	1
Tetralogy of Fallot repair	3	2
Fontan procedure	15	4
Fontan + valve repair	1	2
Glenn operation	5	1
Hypoplastic left heart syndrome biventricular conversion	0	1
Interrupted aortic arch	0	1
Jatene procedure	0	4
Mitral valve repair	2	1
Mitral valve repair + pulmonary banding	1	0
Norwood operation	0	2
Pulmonary stenosis	1	1
Pulmonary valve replacement	1	1
Rastelli procedure	1	3
Subaortic ridge	3	1
Subaortic ridge + mitral repair	1	1
Ross procedure	1	1
Right ventricle outflow tract reconstruction+ pulmonary valve replacement	1	3
Shone complex	0	2
Total anomalous pulmonary venous return	1	0
Ventricular septal defect	4	2
Ventricular septal defect + aortic coarctation repair	1	1
Ventricular septal defect + pulmonary stenosis	1	3
Warden procedure	2	0

Table 2. Table of perioperative patient data and the univariate analysis of on-table extubation

	Patients (n=114)				Group 1 (n=64)				Group 2 (n=50)				
	n	%	Median	IQR	n	%	Median	IQR	n	%	Median	IQR	*p*
Age (month)			25.25	57.46 - 4.35			34.6	59.44 - 9.8			8.06	50.85 - 2.3	0.159
Weight (kg)			10	16 - 5.35			12	16 - 7.65			5.75	14.12 - 3.97	0.088
Body surface area (m^2)			0.48	0.66 - 0.29			0.56	0.70 - 0.38			0.30	0.61 - 0.25	**0.020**
Reoperation	52	45.6			32	50			20	40			0.288
Pulmonary hypertension	45	39.4			25	39			20	40			0.919
Cyanosis	65	57			38	59.3			27	54			0.565
STS-EACTS mortality category													**0.003**
Category 1	20	17.5			15	23.4			5	10			
Category 2	51	44.7			36	56.2			15	30			
Category 3	22	19.3			8	12.5			14	28			
Category 4	19	16.7			5	7.8			14	28			
Category 5	2	1.8			0	0			2	4			
STS-EACTS Estimated mortality (%)			3	5.65 - 2.6			3	3.85 - 1.9			4.6	8 - 2.65	**0.009**
STS-EACTS Morbidity score (n)			1.3	1.9 - 0.9			1.2	1.9 - 0.8			1.4	2.22 - 1	**0.005**
STS-EACTS Estimated postoperative length of stay (day)			12	14.9 - 9.22			11.6	14.9 - 8.4			13.05	16.55 - 9.8	**0.007**
STS-EACTS Estimated major complications (%)			7.15	12 - 5.6			7.05	12 - 5			7.85	12.02 - 6.17	**0.040**
Hematocrit level before extubation (%)			31.7	34.8 - 28.47			31.85	34.75 - 29.45			31.2	34.8 - 27.2	0.671
pO_2 level before extubation (mmHg)			167.35	250.22 - 67.45			174.85	284.75 - 90.35			151.65	241.5 - 63.52	0.187
pCO_2 level before extubation (mmHg)			34	38.6 - 38.3			33.35	37.7 - 28.12			35.95	40.15 - 28.95	0.117
Lactate levels before extubation (mmol/L)			2.3	4.22 - 1.6			1.95	3 - 1.42			4.1	5.22 - 2.1	**<0.001**
pH level before extubation			7.37	7.41 - 7.32			7.37	7.42 - 7.32			7.37	7.41 - 7.33	0.537
Fluid balance before extubation (mL)			–25	121.25 - –150			–50	47.5 - –200			57.5	210 - –101.25	**0.003**
Fluid balance/body surface area (mL/m^2)			–65.87	300.7 - –308.14			-106.11	97.38 - –318.08			141	745.99 - –285.84	**0.002**
Cross-clamp time (min)			57	108.25 - 0			39	78.5 - 0			96.5	129.25 - 49.5	**<0.001**
Bypass time (min)			128	178 - 79			105	142.25 - 74			172.5	196.75 - 119.5	**<0.001**
Postoperative hospital length of stay (day)			11	18.25 - 7			9	12 - 6			15	24.5 - 9.5	**<0.001**
Postoperative intensive care unit stay (day)			1	3 - 1			1	2 - 1			3	4.5 - 1	**<0.001**

IQR: Interquartile range; STS-EACTS: Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery.

Table 3. Table of the multivariate analysis

Variables	Significance	Exp(B)	95% CI for exp(B)
STS-EACTS Estimated mortality	0.569	0.927	(1.205-.713)
STS-EACTS Estimated major complication	0.074	0.841	(1.017-.695)
STS-EACTS Estimated postoperative length of stay	**0.035**	**1.266**	**(1.574-1.017)**
Lactate level before extubation	**0.005**	**1.553**	**(2.111-1.143)**
Fluid balance/body surface area	0.264	1.000	(1.001-1.000)
Cross-clamp time	0.228	1.009	(1.023-.995)
Bypass time	0.225	1.008	(1.022-.995)

STS-EACTS: Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery.

difference between the body surface areas. Regarding the cyanotic nature of the pathology, presence of pulmonary hypertension or the reoperation status, there was no significant difference between the two groups ($p>0.05$). None of the five neonates in our cohort could be extubated in the operating room. Of these neonates, two had Norwood Stage 1 operation, two had Jatene procedure, and one had central shunt operation.

The patients were categorized according to STS-EACTS mortality scoring system which indicates the surgical complexity. Accordingly, there was a significant difference between the groups. An increase in the complexity score was negatively correlated with the ability to extubate ($p=0.003$). In this context, operative complexity rate estimates of the STS-EACTS mortality and morbidity scoring systems including estimated mortality, estimated morbidity, estimated postoperative length of stay, and estimated major complication rate were shown to be statistically significant between the groups ($p=0.009$, $p=0.005$, $p=0.007$, and $p=0.04$, respectively). Pertaining to the operative data, as cross-clamp and cardiopulmonary bypass (CPB) times increased, the extubation practicability statistically significantly decreased ($p<0.001$ and $p<0.001$, respectively). On the other hand, in the blood gas analysis taken prior to extubation, the lactate levels were higher in patients who were in Group 2. Additionally, postoperative fluid balance, as well as the ratio of the fluid balance to the body surface area of the patient, were shown to be statistically significant parameters. As an outcome of this strategy, on-table extubation was associated with a decreased ICU and hospital length of stay. There were no mortalities among the patients included in our cohort.

The results of the multivariate analysis showed that STS-EACTS estimated postoperative length of stay and lactate level prior to extubation were significant factors for carrying out on-table extubation ($p=0.035$ and $p=0.005$, respectively) (Table 3). There was a moderate statistically significant and positive correlation between on-table extubation and length of ICU and hospital stay ($r=0.530$, $p<0.001$ and $r=0.20$, $p<0.001$, respectively).

One of the extubated patients in Group 1 was reintubated in the operating room and was put on mechanical ventilation. This patient was extubated on postoperative Day 3. None of the patients were re-intubated during their ICU follow-up.

DISCUSSION

Numerous studies on infants and children have shown the feasibility of the fast-track extubation strategy.[1-3,10] Notably, limited data have been published on the viability and clinical outcome of this strategy in neonates and infants.[1] Younger age has been associated with the prolonged postoperative mechanical ventilation.[2-4,13] In the literature, it is common to exclude the operations performed on newborns in their statistical analysis for fast-track extubation.[2] None of the newborns could be extubated in the operating room in our study. This outcome can be explained by the fact that neonates and infants differ from older children with regards to their central nervous system structure, metabolic maturation, inflammatory response, and surgical complexity which may make this age group susceptible to postoperative complications and a subsequent difficulty in early extubation.[13,14]

The STS-EACTS scoring system provides a preoperative prediction of the complexity of an

operation and, in this context, postoperative follow-up. This prediction can give an idea regarding the medical interventions that would be required to be implemented starting from the first preoperative evaluation, as well as the extubation time of the patient. In our analysis, the surgical complexity score was found to be correlated to extubation. This is not an unexpected association, since an increase in surgical complexity may require for a longer CPB and cross-clamp duration. As evident from the published data, the on-table extubation strategy is more likely to be abandoned in cases with increasing complexity.[1,5,9] This can be attributed to previous data stating that fast-track extubation is safer in surgeries of lower complexity scores.[5] In our analysis, it is evidently clear that fast-tracking in congenital heart surgery is achievable both for simple and complex procedures. Furthermore, the complexity scores may be used as a tool by the clinicians preoperatively to predict the achievability of on table extubation.

The negative impacts associated with prolonged CPB and cross-clamp times impair the patient's ability to be extubated, consistent with our results. Pediatric patients undergoing cardiac surgery with CPB suffer significant physiological stress due to a combination of direct surgical damage, ischemia-reperfusion injury, and systemic inflammation associated with poor respiratory compliance, acute lung injury, and coagulopathy.[2,4,14] Additionally, it has been shown that there is a substantial shift in the metabolic profile of these patients undergoing cardiac surgery with CPB that indirectly affect the ability to be extubated.[14] Furthermore, increased cross-clamp time and the resultant ischemia has been linked with myocardial dysfunction following bypass along with several other causes, including an inflammatory response, hypothermia, and ventriculotomy.[15] Therefore, a prolongation either of these parameters may be suggestive of delayed extubation.

Fluid overload has been shown to be independently associated with adverse outcomes in congenital heart surgery patients.[16,17] Maintaining negative fluid balance to achieve permissive hypovolemia is one of the most crucial strategies to reduce pulmonary edema, prevent intravascular volume overload, and lessen multiple-organ dysfunction, particularly in low-weight patients.[13,16,17] Thus, a parameter calculated by the total fluid balance of the patient divided by the body surface area was also included in our analysis and was found to be statistically significant. This parameter was included in consideration of the direct impact of the volume status of the patient on their respiratory capacity. The clinical impact of a given total fluid balance would vary in-between age groups given their highly varying body surface areas. Therefore, we found it appropriate to make fluid balance comparable within groups in our analysis. This value was previously found to be a significant and independent risk factor for prolonged postoperative ventilation.[13] Therefore, this parameter can possibly give an insight into the practicability of on-table extubation.

Previous studies have shown that higher arterial lactate levels during the intraoperative phase are related with increased rates of complications and early postoperative lactate values are an independent predictor of mortality.[18-20] This correlation can be attributed to many factors that cause discrepancies between metabolic needs of organ systems and the oxygen supply to cells including inadequacies in the CPB pump flow, systemic and pulmonary vasomotor changes, significant hematocrit decline, increased oxygen consumption during reheating, and inflammatory response escalation.[18,19] Following bypass, with the re-establishment of the physiological circulation, we can speculate the insufficiency of the oxygenation and cardiac performance from the high lactate levels. Consistent with the literature, our study yielded an association between higher lactate levels and prolonged need for postoperative mechanical ventilation.

As previously published compelling evidence has established, early extubation and fast-track extubation result in shorter hospital stays.[3,5,7,8,10] Moreover, evident from the results of our analysis, there is an association between on-table extubation and earlier discharge times associated with shorter hospital and ICU length of stay with moderate correlation.

A patient specific approach is critical in fast-tracking. Perioperative parameters must be weighed in the decision-making process. The anesthetic method used should allow the anesthesiologist to base their decision to whether proceed with fast-track extubation or not in a specific patient not only on preoperative variables, but also to maintain this option open until the surgery is completed.[4,9] If, at the end of the operation, intraoperative variables such as a long bypass and cross-clamp time, high inotropic support requirement, uncontrolled hemorrhage, or any other factor preventing fast-track extubation and early extubation are present, the anesthesia can be modified to allow the transfer of the patient to the ICU.[4] For fast-tracking, the postoperative ICU care of the patients is also critical. Factors such as the postoperative total fluid balance, pain management and sedation are all determinants of the achievability of this strategy.

The main limitation to this study is that it is a single-center, retrospective observational study with a relatively small cohort, particularly with regards to the number of neonates. It can be difficult to discern in retrospect, if the claimed patient group truly intended to be extubated and whether any specific patient's circumstances precluded extubation. The decision to extubate is made in a case-based approach rather than from a fixed extubation criteria given the variability of the pathologies. Furthermore, we consider that the complexity scores might not adequately predict the true complexity of a patient in every case.

In conclusion, a coordinated interdisciplinary approach is required for the implementation of a safe fast-tracking strategy. Longer cardiopulmonary bypass and cross-clamp times and increased surgical complexity are negative predictors of on-table extubation. Higher lactate levels in the blood gas analysis taken prior to extubation and a higher operative fluid balance per unit body surface area may indicate a failure to extubate. The implementation of an on-table extubation strategy is associated with overall reduced intensive care unit and hospital length of stays.

Ethics Committee Approval: The study protocol was approved by the Koç University Ethics Committee (date: 28.07.2022, no: 2022.256.IRB1 .097). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from the parents and/or legal guardians of the patients.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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