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Analysis of ST segment alarms in children admitted to the paediatric and cardiac intensive care units and cardiac progressive care unit: a single-centre retrospective study

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Abstract

ST segment monitoring in the adult population allows for the early detection of myocardial ischaemia. In children admitted to the paediatric intensive care unit (PICU), cardiac intensive care unit (CICU), and cardiac progressive care unit (CPCU), it is unclear if continuous ST segment alarm monitoring is necessary in all patients. All patients admitted to the PICU, CICU, and CPCU during the study period were included. Children with any ST segment alarms were compared with those without an alarm during their stay. The electrocardiogram confirmed true ST segment alarms were compared with all other ST segment alarms. Demographic and clinical data were extracted from the medical record. Medical interventions and procedures occurring around ST segment alarms were recorded for multivariable analysis assessing for the association of true ST segment. Logistic regression was used to evaluate the associations with ST segment alarms during hospital stays. ST segment alarms occurred in 36% of hospital stays, and only 3.4% were considered true. True alarms were significantly more common among patients with a cardiac-related diagnosis, located in both cardiac units, and having received an intervention with any vasoactive medication. In the multivariable logistic regression, patients 11 years or older, hypotension, supraventricular tachycardia, and initiation/escalation of any vasoactive were independently associated with a true ST segment alarm. True ST segment alarms were infrequent, occurring in 1.2% of stays during the study period. Alarm monitoring may be beneficial in those with an underlying cardiac diagnosis.

ST segment alarm monitoring in adults can provide informative and actionable information pertaining to new or ongoing myocardial ischaemia.[1–5] The American Heart Association has published evidence-based electrocardiographic monitoring guidelines for patients at risk for myocardial ischaemia.[4] The American Association of Critical Care Nurses published a practice alert to ensure accurate ST segment monitoring for patients in 2016 encompassing education for accurate clinical decision-making.[6] While some paediatric children may be at risk for myocardial ischaemia, parallel guidelines and practice alerts do not exist.[7,8]

Cardiorespiratory monitoring is considered the standard of care for children admitted to ICU and cardiac step-down settings. ST segment monitoring at Children's Hospital Colorado was implemented for all patients in 2012 who were admitted to the paediatric intensive care unit (PICU), cardiac intensive care unit (CICU), and cardiac progressive care unit (CPCU) following an event review of a patient safety event where ST segment monitoring was not utilised. This implementation did not consider the lack of evidence supporting ST segment monitoring in the paediatric population. Alarm fatigue occurs when clinicians are desensitised by alarms, many of which may be non-actionable or invalid.[9] The Joint Commission's National Patient Safety Goals now require hospitals to evaluate risks of alarm mismanagement related to alarm fatigue.[10] Alarms need to be set at actionable levels and individualised for a patient, so when one occurs, it is meaningful and handled expeditiously.[11]

Because of the perceived increase in cognitive load and alarm fatigue, we sought to better understand the true burden of ST segment alarm monitoring. The purpose of this study was to describe the incidence of ST segment alarms across these three units and determine the factors associated with true ST segment alarms. We hypothesised that there would be a high rate of false alarms in all three units, and there would be specific factors associated with true ST segment alarms.

Material and methods

Design and setting

We performed a single-centre retrospective cohort study including all patients admitted to the PICU, CICU, and CPCU from May 1 to July 31, 2016. Patients were categorised and compared across two groups: those who had at least one ST segment alarm and those who did not have any ST segment alarms during their stay. We included multiple stays in ICUs of patients during the study period.

Data collection

Patient demographics, clinical data, and outcomes (length of stay, death) were extracted from the electronic medical record. The International Classification of Diseases codes were used to classify patients by primary diagnoses (Supplementary Table A). "True" ST segment alarms were defined as those having both an ST segment alarm and a 12-lead electrocardiogram demonstrating ST segment abnormalities. Because multiple alarms can occur within a short period of time, we grouped alarms into clusters for analysis. An alarm cluster included all alarms that occurred within a 15-minute period from the start of another alarm. We evaluated for and extracted data on medical interventions and procedures occurring in the hour prior to the start of an alarm cluster. Medical interventions included fluid boluses and initiation or titration of vasopressors. Procedures included intubation and placement of invasive lines and/or drains, scopes, or taps. Adverse outcomes were evaluated and included code events in all three units, rapid response team evaluations for cardiac progressive care patients, or death if they occurred within 12 hours after the end of an alarm cluster. For those patients identified as having an intervention, procedure, or adverse outcome associated with an alarm cluster, additional chart reviews were conducted to determine if the interventions or outcomes were plausibly related to the ST segment alarm.

Statistical analysis

Stays in the CICU and CPCU were analysed together as these units represent a continuum of care. Analyses were conducted in two ways. We compared any patient with an ST segment alarm or alarm cluster to those with no ST segment alarms. Second, we compared "true" ST segment alarms to any false ST segment alarms. In both analyses, categorical variables are reported as proportions and continuous variables as median with interquartile range. All analyses accounted for the clustering of hospital stays within a patient. Categorical variables were compared using design-adjusted Pearson chi-square tests, and continuous variables were compared using nonparametric median tests. Multivariable logistic regression was used to determine the associations with (1) an ST segment alarm and (2) a "true" ST segment alarm with robust variance estimators. Any variables from the bivariate analyses that were significant at $p < 0.05$ and could be known at the beginning or during the hospital stay were included into the logistic regression models. Multicollinearity was encountered between the predictors, specifically the International Classification of Diseases codes. We eliminated one variable of each pair of the International Classification of Diseases codes with a tetrachoric correlation > 0.4 so that ultimately only gastrostomy status, dehydration, current long-term use aspirin, atrial septal defect, secondary pulmonary hypertension, and supraventricular tachycardia were included in the International Classification of Disease codes in the first model. We also included an interaction effect between the ICU type and the number of cardiac-related International Classification of Diseases codes since paediatric children with cardiac complexities will be automatically admitted to the either cardiac unit. Due to the rarity of true ST segment alarms and the therefore small analytic sample size, we limited the number of predictors in our second logistic regression to six: age, ICU type, the number of cardiac-related International Classification of Diseases codes, two cardiac-related International Classification of Diseases codes, and an indicator for any vasopressor medication given within an hour before the alarm cluster. Logistic regression coefficients are reported as odds ratios with 95% confidence intervals. A p-value <0.05 was considered statistically significant. All statistical analyses were conducted using Stata/SE 17.0 (StataCorp LP, TX).

Results

There were 801 unique patients with 885 stays during the study period. Data from 20 stays were not included due to data integrity issues. Among the entire population, there was a greater proportion of males (54.5%), with 65% of stays occurring in the PICU. Any cardiac-related International Classification of Diseases code was reported in 54.8% of the population, with atrial septal defect (11.6%), hypotension (6.8%), primary hypertension (6.7%), and secondary pulmonary hypertension (6.7%) being the most common. The most common non-cardiac International Classification of Diseases codes were gastrostomy status (13.6%), gastroesophageal reflux (11.8%), acidosis (11%), and hypoxaemia (11%). The median length of stay among the entire cohort was 5 days (IQR: 2, 10 days).

ST segment alarms

ST segment alarms occurred in 296 patients encompassing 323 stays. There were 530 patients (562 stays) with no ST segment alarms. The overall prevalence of any ST segment alarm during the 885 stays was 36.5% ($n = 323$). Among the entire cohort, ST segment alarm clusters occurred a median of 0 times (IQR: 0, 2; range: 0, 59). The total number of ST segment alarm clusters was 2048. The median alarm cluster duration was 5.4 minutes (IQR: 0.7, 20.2 minutes). The longest ST segment alarm cluster lasted 8.5 hours. Among those with ST segment alarms, there was a greater proportion of males (59.8% versus 51.4%, $p = 0.02$) who were most often <1 year ($p = 0.001$), were admitted to the cardiac units (53.9% versus 24.2%, $p < 0.001$), and had a greater number of cardiac-related International Classification of Diseases codes (median 2 [IQR 0, 3] versus median 0 [IQR 0, 2]; $p < 0.001$). Those with an ST segment alarm stayed in the hospital a median of 2 days longer compared with those without an ST segment alarm ($p < 0.001$). Clinicians ordered an electrocardiogram during 84 of the 2048 alarm clusters (4.1%).

The overall prevalence of true ST segment alarms was 1.2% ($n = 11/885$). Among those patients with an ST segment alarm during their stay, the incidence of a true alarm was 3.4% ($n = 11/323$). Ten of the 11 patients with a true alarm were admitted to the cardiac units. Table 1 summarises the demographics and characteristics of patients with true ST segment alarm versus any ST segment alarm. There was no difference in the occurrence of any invasive procedures around a true ST segment alarm. Vasoactive medications were initiated or increased in a greater proportion of patients with a true ST segment alarm compared to those with any ST segment alarm (36.4% versus 6.1%, $p < 0.001$).

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Table 1. Patient and hospital stay characteristics as well as procedures, interventions, and outcomes overall and by occurrence of true ST segment alarms during stay

Characteristic	Overall n %	True ST segment alarm during ICU stay % (n)		P-value
		No (n = 312)	Yes (n = 11)	
Sex				0.372
Male	193 (59.8)	185 (59.3)	8 (72.7)	
Female	130 (40.3)	127 (40.7)	3 (27.3)	
Age group				0.618
Less than 1 year	123 (38.1)	120 (38.5)	3 (27.3)	
1–5 years	96 (29.7)	93 (29.8)	3 (27.3)	
6–10 years	37 (11.5)	36 (11.5)	1 (9.1)	
11 years or more	67 (20.7)	63 (20.2)	4 (36.4)	
Length of stay in days	6.8 (3.2–21.7)	6.6 (3.3–21.4)	17.6 (5.8–72.1)	0.216
ICU type				0.012
Any CICU/CPCU	174 (53.9)	164 (52.6)	10 (90.9)	
PICU only	149 (46.1)	148 (47.4)	1 (9.1)	
Any cardiac-related ICD-10 code				0.021
Yes	222 (68.7)	211 (67.6)	11 (100.0)	
No	101 (31.3)	101 (32.4)	0 (0.0)	
Cardiac-related ICD-10 codes	2 (0–3)	2 (0–3)	3 (2–6)	0.144
10 most common diagnoses from ICD-10 codes				
Gastrostomy status	56 (17.3)	54 (17.3)	2 (18.2)	0.939
Gastroesophageal reflux	49 (15.2)	49 (15.7)	0 (0.0)	0.150
Atrial septal defect	69 (21.4)	65 (20.8)	4 (36.4)	0.216
Acidosis	36 (11.2)	34 (10.9)	2 (18.2)	0.451
Hypoxaemia	40 (12.4)	39 (12.3)	1 (9.1)	0.737
Acute respiratory failure and hypoxia	37 (11.5)	36 (11.5)	1 (9.1)	0.802
Acute kidney failure	40 (12.4)	37 (11.9)	3 (27.3)	0.127
Family history of asthma, etc.	32 (9.9)	32 (10.3)	0 (0.0)	0.256
Dehydration	22 (6.8)	22 (7.1)	0 (0.0)	0.366
Current long-term aspirin use	39 (12.1)	37 (11.9)	2 (18.2)	0.512
10 most common cardiac-related diagnoses from ICD-10 codes				
Atrial septal defect	69 (21.4)	65 (20.8)	4 (36.4)	0.216
Hypotension	22 (6.8)	19 (6.1)	3 (27.3)	0.006
Primary hypertension	26 (8.1)	22 (7.1)	4 (36.4)	<0.001
Secondary pulmonary hypertension	33 (10.2)	30 (9.6)	3 (27.3)	0.059
Ventricular septal defect	33 (10.2)	32 (10.3)	1 (9.1)	0.900
Hypoplastic left heart syndrome	32 (9.9)	31 (9.9)	1 (9.1)	0.925
Patent ductus arteriosus	29 (9.0)	29 (9.3)	0 (0.0)	0.278
Stenosis of pulmonary artery	18 (5.6)	17 (5.5)	1 (9.1)	0.608
Coarctation of aorta	16 (5.0)	16 (5.1)	0 (0.0)	0.436
Supraventricular tachycardia	18 (5.6)	15 (4.8)	3 (27.3)	0.002
Procedures				
Intubation (any)	3 (0.9)	3 (1.0)	0 (0.0)	0.743
Lines, drains, tubes (any)	4 (1.2)	4 (1.3)	0 (0.0)	0.704

(*Continued*)

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Table 1. (*Continued*)

Characteristic	Overall n %	True ST segment alarm during ICU stay % (n)		P-value
		No (n = 312)	Yes (n = 11)	
Scopes (any)	0 (0.0)	0 (0.0)	0 (0.0)	1.00
Taps (any)	1 (0.0)	1 (0.3)	0 (0.0)	0.851
Any procedure	8 (2.5)	8 (2.6)	0 (0.0)	0.588
Intervention				
Vaso (any)	23 (7.1)	19 (6.1)	4 (36.4)	<0.001
Fluids (any)	17 (5.3)	16 (5.1)	1 (9.1)	0.563
Any intervention	34 (10.5)	30 (9.6)	4 (36.4)	0.005
EKG				
Performed (any)	73 (22.6)	62 (19.9)	11 (100.0)	<0.001
Abnormal (any) (n = 73)	50 (68.5)	39 (62.9)	11 (100.0)	0.083
Outcomes				
Code (any)	8 (2.5)	8 (2.6)	0 (0.0)	0.586
RRT (any)	3 (0.9)	3 (1.0)	0 (0.0)	0.759
Death	3 (0.9)	3 (1.0)	0 (0.0)	0.743
Any outcome	12 (3.7)	12 (3.9)	0 (0.0)	0.519
Death during hospital stay outside ST segment alarm period	9 (2.8)	8 (2.6)	1 (9.1)	0.202

Continuous variables are reported as median with interquartile range. Categorical variables are presented as frequency (%). CICU = cardiac intensive care unit; CPCU = cardiac progressive care unit; EKG = electrocardiogram; ICD = International Classification of Diseases; PICU = paediatric intensive care; RRT = rapid response team.

Clinical deterioration was evident in the chart prior to the beginning of any of the 11 true ST segment alarm clusters.

Associations with ST segment alarms

Several factors remained significant predictors of an increased chance of having any ST segment alarm during the ICU stay in a multivariate logistic regression: being male (adjusted odds ratio [aOR] 1.53, p = 0.010), having a gastrostomy status (aOR 1.70, p = 0.032) and the number of cardiac diagnoses while staying in the cardiac units compared to the PICU (aOR 1.57 [main and interaction effects with 1 condition], p = 0.049). Any age group compared to patients less than 1 year is significantly less likely to experience an ST segment alarm (aOR 0.44 for 1–5 years, AOR 0.33 for 6–10 years, AOR 0.29 for 11 years or more, all p < 0.001).

In the multivariable analysis, after adjusting for confounding variables, male sex, age >1 year, the interaction between admission location and the number of cardiac-related International Classification of Diseases codes, as well as gastrostomy status, were all independently associated with any ST segment alarm (Table 2).

In the multivariable analysis assessing for the association with true ST segment alarms, only hypotension (aOR 8.25; 95% CI 1.64–41.42; p = 0.01), a diagnosis of supraventricular tachycardia (aOR 7.44; 95%CI 1.29, 42.87; p = 0.03), and any vasoactive initiation or increase (aOR 5.09; 95% CI 1.34–19.38; p = 0.02) were independently associated with an ST segment alarm.

Discussion

Setting alarm thresholds may be particularly challenging in children due to the range of physiologic normative values that exist across age ranges. Our finding that ST segment alarms occurred in just over a third of patients, of which only a small fraction were true positives, suggests the potential to more effectively and safely reduce alarm burden by only activating ST segment monitoring in those at the highest risk for coronary ischaemia. We identified having an underlying cardiac diagnosis and admission to either cardiac unit was associated with a true ST segment alarm in univariate analyses. However, in the multivariate analysis, neither admission unit nor the proportion of cardiac-related diagnostic codes was independently associated with a true ST segment alarm. We found patients with cardiac-related diagnostic codes of hypotension and supraventricular tachycardia had a significantly greater odds of having an ST segment alarm. Hypotension may contribute to coronary ischaemia, particularly if it is diastolic in nature as the coronary arteries are predominantly perfused during diastole. Supraventricular tachycardia may result in ST segment changes and alarms because of the possibility of reduced coronary perfusion during tachycardia that is not manifested until the restoration of sinus rhythm. Certainly, there are cardiac conditions in which ST segment monitoring should be considered. These include any patient who has recently undergone cardiac surgery with coronary manipulation/reimplantation such as the transposition of the great arteries or Ross procedure. ST segment monitoring should be considered for those patients with coronary anomalies including right ventricular-dependent coronary circulation as seen in pulmonary atresia with intact ventricular septum or systemic run-off lesions (e.g. severe aortic insufficiency or systemic to pulmonary artery shunts). Interestingly, the initiation or escalation of a vasoactive infusion in the hour prior to the ST segment alarm was also associated with an alarm. While one could assume that the initiation of a vasoactive resulted in an ST segment alarm, we postulate that there was awareness of a deteriorating patient, and the ST segment alarm might have occurred regardless.

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Table 2. Logistic regression model predicting any ST segment alarm during stay

	Adjusted odds ratio	95% confidence interval	P-value
Sex (ref: female)			
Male	1.53	1.11–2.10	0.010
Age group (ref: <1 year)			
1–5 years	0.44	0.28–0.67	<0.001
6–10 years	0.33	0.19–0.56	<0.001
11 years or more	0.29	0.18–0.45	<0.001
ICU type (ref: PICU)			
Any CICU/CPCU	1.27	0.77–2.08	0.347
Number of cardiac-related ICD-10 codes	1.04	0.86–1.27	0.663
Interaction effect between ICU type and number of cardiac-related ICD-10 codes	1.26	1.00–1.58	0.049
Non–cardiac diagnoses from ICD-10 codes			
Gastrostomy status	1.70	1.05–2.78	0.032
Dehydration	0.77	0.45–1.31	0.333
Current long-term aspirin use	0.84	0.47–1.48	0.544
Cardiac diagnoses from ICD-10 codes			
Atrial septal defect	1.25	0.71–2.20	0.443
Secondary pulmonary hypertension	1.27	0.67–2.43	0.464
Supraventricular tachycardia	1.06	0.35–3.18	0.917

CICU = cardiac intensive care unit; CPCU = cardiac progressive care unit; ICD = International Classification of Diseases; PICU = paediatric intensive care unit.

ST segment alarms in PICU patients in those without a cardiac-related diagnostic code had a median number of three alarms per alarm cluster or 900 alarms in a 3-month period, accounting for about three alarms per day from this metric only. Had these patients not had ST segment monitoring, 293 out of the 2048 alarm clusters (14.3%) would have not occurred, and there likely would not have been any near-miss events. Because of this information, the PICU no longer defaults to routine ST segment monitoring for all patients, and protocols are being developed to identify what patients should be monitored. Unfortunately, this decision-making is not as simple in the CICU and CPCU. While specific anatomic cardiac abnormalities or cardiac operations dictate the need for ST segment monitoring as previously discussed, further studies that identify those at the highest risk are needed. This will allow for the development of protocols that could standardise care across institutions and tie with other quality improvement initiatives such as the Pediatric Cardiac Critical Care Consortium cardiac arrest prevention programme.[12]

The strengths of this study are its cross-unit evaluation, potentially capturing heterogeneous populations at risk for true ST segment alarms. There are, however, several limitations. First is the retrospective design, from which we can only infer associations, not causality. Second, electrocardiograms were performed in less than 25% of ST segment alarms, which could have resulted in failure to identify a true alarm. Third, we did not have the ability to capture electrode placement or review waveforms other than what was evaluated by electrocardiograms. Finally, we did not capture nursing and provider perceptions of alarm fatigue. In paediatric children without a known high-risk cardiac diagnosis, ST segment alarm monitoring is unlikely to identify true clinical deterioration and can be a significant contributing factor to alarm fatigue. Further studies that delineate those at the highest risk for coronary ischaemia are needed to develop protocols to reduce nuisance alarms and thus cognitive overload. Future studies that integrate existing machine learning algorithms using physiologic waveform data are also needed to reduce alarm fatigue and identify patient deterioration.

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Competing interests. None.

Ethical standard. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national guidelines on CITI human experimentation and with the Helsinki Declaration of 1975, as revised in 2008, and have been approved by the Colorado Multiple Institutional Review Board with a waiver of informed consent (COMIRB# 17-0031).

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