The role of EEG recordings in children undergoing cardiac surgery for congenital heart disease

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Abstract. Neurological dysfunction may occur after corrective cardiac surgery using cardio-pulmonary bypass (CPB) with or without circulatory arrest. Different neurophysiological monitoring systems have been employed to detect neurological complications and possible brain injury in infants and children during and after cardiac surgery. The value of EEG in infants and children at risk for neurological sequelae has not been systematically studied.

Sequential performance of 2 EEGs before and after cardiac surgery at a tertiary University Hospital to screen for possible brain injury after cardiac surgery. In addition, a complete neurological examination was performed.

In 313 patients (age: 54.2 ± 55.7 months; normal initial EEG) after cardiac surgery CPB (duration of surgery: 146.0 ± 58.9 minutes; aortic cross clamp time: 34.1 ± 19.1 minutes) a 19-channel EEG recording was performed 2.4 ± 1.8 days prior and 11.6 ± 5.3 days after cardiac surgery. An abnormal EEG was detected in only 8 of 313 patients (2.5%; focal slowing(1), generalised slowing (5), epileptiform discharges(2)) after cardiac surgery, while the EEG was normal in the remaining 305 patients (97.5%). In one patient, an intra-cerebral pathology was seen on MRI (ischemic); in 5 patients follow-up EEGs were performed, which revealed normalised findings. None of the 8 patients demonstrated new focal neurological deficits on physical examination, but 33 (9.7%) children demonstrated minor abnormalities (eg, subtle motor asymmetry, increase in muscle tone, etc.), which were unrelated to abnormal EEG findings.

According to the used protocol pathological EEG findings were very infrequent in our study cohort. The routine and indiscriminate recording of EEGs in children before and after corrective or palliative cardiac surgery for congenital heart disease using CPB is not recommended. Further intra-operative neuromonitoring methods with immediate intervention should be evaluated.

Keywords: Congenital heart disease, cardiac surgery, cardiopulmonary bypass, electroencephalography, children, neurological sequelae

Introduction

Neurological and psychomotor deficits still occur in pediatric patients after surgery of congenital heart disease with cardiopulmonary bypass (CPB) with or

without periods of deep hypothermic circulatory arrest [1,2]. The etiology of cerebral injury associated with cardiac surgery in neonates and infants is considered as multifactor and has not been clearly elucidated [1,3–5]. Visible brain lesions such as intracranial hemorrhages and non-visible lesions resulting in long-term neuropsychological and cognitive deficits have been reported in association with congenital heart malformations and corrective cardiac surgery [6–9]. However, the precise etiology and time course both global or focal brain injury remains a matter of debate. In addition to possible

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congenital brain abnormalities a causal relationship has been suggested between the neurological sequelae and several non-physiological factors during corrective cardiac surgery such as variations in blood flow, oxygenation, temperature and acid-base status [10,11]. Postoperatively hyperventilation, low cardiac output syndrome, and variation in intravascular volume during the early postoperative period contribute to alterations in cerebral hemodynamics and thereby to the possible development of cerebrovascular injury [12,13]. Several cerebral imaging modalities may be used to detect abnormal intracranial findings before and after surgery. However, these methods are not routinely used in all neurologically asymptomatic infants and children undergoing cardiac surgery. Certainly, in neonates and infants transcranial ultrasound is used routinely to detect possible intraventricular or periventricular hemorrhage.

A strong predictive value of adverse neurological and developmental outcome at 1 year of age was found in those infants who had evidence of seizure activity during the first 48 postoperative hours after corrective cardiac surgery [14]. The value of using routine EEG to assess abnormal cerebral activity before and after surgery in large groups of patients undergoing corrective or palliative cardiac surgery has not been formally reported as of now.

The aim of this study was to assess the role of routine EEG recordings prior and after cardiac surgery to detect neurophysiological abnormalities, and to relate the EEG findings to clinical findings on neurological examination.

Patients and methods

This study was done in accordance with the policy of the Institutional Review Board and Ethics Committee of the University Hospital of Saarland, Homburg, Germany. Parental consent was obtained prior to enrolment.

All patients with planned/elective corrective or palliative cardiac surgery using CPB in our department were enrolled in this study, and their data (age, gender, type of cardiac lesion, type and length of surgery, time of aortic cross clamp, results of EEG studies, and results of neurological examination) were retrieved from an electronic database. The recording of EEGs before and after cardiac surgery was routine practice in our hospital.

Enrolment criteria: Patients (aged 0–17 years) admitted to our hospital for planned corrective/palliative cardiac surgery. All data were stored using SPSS 17.0 software. Data are presented as mean $\pm$ standard deviation.

EEG recordings

A 19-channel EEG recording was performed prior to cardiac surgery and before PICU/hospital discharge. Only children with a normal initial EEG were included in this study. In addition, a complete neurological examination was performed before discharge.

Twenty silver cup electrodes were placed according to the 10–20 international system. Electrode impedances measured less than 5 kOhm. An IT med[®] (IT Medical, Usingen, Germany) model EEG Neurofile NT/XP machine was used to record 12 channels. A high-frequency channel was set at 70 Hz; bipolar longitudinal and transversal montages were used. Each EEG recording lasted 15–20 min. All EEGs were evaluated by the same experienced neuropsychiatrician (MGS), based on conventional EEG criteria. Age-dependent EEG differences were taken into account [15].

Abnormal EEG findings were divided into 3 categories: a) focal slowing b) generalised slowing c) epileptiform discharges (Fig. 1a–c).

Prior to discharge and after recording of the second EEG a formal clinical neurological examination was performed to look for specific neurological deficits. We did not assess cognitive function before discharge. Also, we did not routinely perform other studies to search for neurological abnormalities (biomarkers, imaging studies, etc.).

Results

Between January 2004 and January 2008 a total of 313 patients (mean age: 54.2 ± 55.7 months) undergoing cardiac surgery with CPB (duration of surgery: 146.0 ± 58.9 minutes; aortic cross clamp time: 34.1 ± 19.1 minutes) were included in this study (58 ASD; 72 VSD, 33 Fallot, 51 valve anomalies; 19 TGA, 15 AV canal, 65 other complex anomalies including single ventricle etc.).

Surgical procedures included a variety of procedures, eg, closure of atrio-septal defects, ventricular septal defects, arterial switch surgery for transposition of the great arteries, Norwood stage I surgery, Hemi-Fontan, Fontan, Glenn procedure, Damus-Kaye-Stensel surgery, and pulmonary and aortic valve replacement or reconstruction.

A 19-channel EEG recording was performed 2.4 ± 1.8 days prior and 11.6 ± 5.3 days after cardiac surgery. An abnormal EEG was detected in only 8 of 313 patients (2.5%; focal slowing (1), generalised slowing (5), epileptiform discharges (2)) after cardiac surgery, while the EEG was normal in the remaining 305 patients

(97.5%). In one patient, an intra-cerebral pathology was seen on MRI (ischemic lesion); in 5 patients follow-up EEGs were performed, which revealed normalised findings. Three patients did not present for the recording of a follow-up EEG. No significant differences between children with EEG abnormalities and normal EEGs were seen with regard to underlying disease, type and length of surgery, and aortic cross clamp time. None of the 8 patients demonstrated new neurological abnormalities or deficits on physical examination; however, 33 (9.7%) children demonstrated minor abnormalities (eg, subtle motor asymmetry, increase in muscle tone, etc.), which were unrelated to abnormal EEG findings. Again, this group was not significantly from children without minor neurological abnormalities with regard to underlying disease, type and length of surgery, and aortic cross clamp time.

The occurrence of an abnormal EEG was not associated with a specific type of surgical procedure nor was it linked to CPB or aortic cross clamp time.

On neurological examination, we did not detect any new focal/specific neurological deficits in any patient that was related to the recent cardiac surgery. None of the patients developed overt clinical seizure activity. As we did not perform neuropsychological testing, we could not assess neuro-cognitive function prior to discharge. Also, we could not rule out very subtle neurological deficits.

Discussion

Electrophysiological techniques are among the most frequently used methods to provide information about the functioning of the human brain [16]. These techniques are useful in that they are non-invasive and relatively inexpensive. The main result of our study demonstrated a low incidence of abnormal EEG findings after surgery in pediatric patients undergoing heart surgery for congenital heart disease. Of interest, in none of our patients did we detect focal or generalized neurological deficits. This can be attributed to the fact that the routine use of CPB during pediatric cardiac surgery has been optimized and is almost completely safe in all mild and complex surgical procedure.

Although, the conducted EEG monitoring before and after cardiac surgery may not necessarily reflect the cerebral monitoring of critical period during and immediately after CPB, we did not detect overt focal neurological deficits in the studied patients, thus giving evidence to no new focal or global cerebral ischemic events. Of note, only few studies have assessed the role

of intra-operative EEG monitoring in children undergoing open-heart surgery.

A very recent study by *Andopoulos et al.* assessed the occurrence of electroencephalographic seizures after neonatal cardiac surgery with high-flow “cardiopulmonary bypass” [17]. In their study, the authors demonstrated that EEG seizures are infrequent (1.5%) in neonates undergoing surgery with high-flow CPB, irrespective of single ventricle or 2-ventricle underlying congenital heart disease. This is to some degree comparable to our findings. Given the low incidence, the authors question the utility of EEG seizures as a marker of acute brain injury, and also as a potential surrogate parameter for long-term neurological outcome [17]. This is an important finding as seizure activity during the first 48 postoperative hours after corrective cardiac surgery has been postulated to be a strong predictive value of adverse neurological and developmental outcome at 1 year of age [14].

Our study was not aimed to monitor the brain physiology during CPB or immediately after surgery, when the patients were under sedation, but rather to screen for possible brain events before discharge. Intra-operatively the standard EEG with 12 channels has been used to monitor brain electrical activities during and after heart surgery in congenital heart surgery with contradictory results [18,19]. In the study by *Austin et al.*, EEG, transcranial Doppler ultrasonic measurement of middle cerebral artery blood flow velocity, and transcranial near-infrared cerebral oximetry were monitored in 250 patients, and an intervention algorithm was developed to detect and correct specific deficiencies in cerebral perfusion or oxygenation or to increase cerebral tolerance to ischemia or hypoxia. From their experience the authors concluded that interventions based on neurophysiologic monitoring appeared to decrease the incidence of postoperative neurologic sequelae and reduce the length of stay [18]. Conversely, *Miller et al.* analyzed the intraoperative EEG changes during open heart surgery with deep hypothermia in 66 infants aged 6 months or younger, 70% of whom were neonates in a prospective study [19]. The authors compared suppression of amplitude and continuity at the nadir of temperature reduction and following rewarming, and the appearance of periodic paroxysmal activity with neurologic abnormalities before and following operation, patient characteristics, and operation variables. Of interest, EEG changes did not disclose any relationship to abnormal neurologic findings, age at operation, type of anesthetic, duration of CPB, duration of low-flow CPB or cooling, temperature at circulatory arrest or low flow, or nasopharyngeal-venous return temperature differences.

The routine recording of an EEG during cardiac surgery is challenging because of interference of the registered signals by several factors during CPB such as, sedative and analgesic medications, hypothermia and re-warming, variation of cerebral perfusion on CPB, and deep hypothermic circulatory arrest. The complexity to place the electrodes in right and stable position during such major heart operations may represent an additional limitation to use the methods for routine brain monitoring during cardiac surgery.

Other methods for cerebral monitoring during and after cardiac surgery have emerged in recent years, including NIRS, sonographic and ultrasound studies as well as the use of biochemical markers (eg, neuron-specific enolase, S100B protein [20]. However, the role of these new modalities in these complex clinical settings has not yet been fully established [21–23].

In summary, our study demonstrated that the studied infants and children did not develop new focal neurological deficits after cardiac surgery according to basic clinical/neurological assessment and EEG monitoring, although a substantial percentage of children developed minor abnormalities when assessed by a physiotherapist. These findings were unrelated to abnormal EEG findings.

We conclude that the long term effect of corrective cardiac surgery and possible altered psychomotor development in association with congenital heart defects should be evaluated using other clinical test. A shortcoming of our study was the fact that we did not formally perform neuro-cognitive functioning tests (eg, Kaufmann-ABC) to detect intellectual deficits secondary to cardiac surgery. Moreover, subtle changes/deficits in their neurological performance may have not been noticed. Of note, most of the included patients were elective or semi-elective patients, and we could not include emergency patients (as the “routine” recording of a baseline EEG is not feasible in this cohort of patients) who are at higher risk of developing neurological dysfunction. Also, we only recorded one follow-up EEG after cardiac surgery. Thus, the true incidence of post-operative EEG abnormalities including seizure activity may be under-estimated in our study.

We conclude that routine EEG monitoring may not be indicated in children undergoing cardiac surgery. An individual approach for children with a high risk for neurological complications and long-term sequelae may be more promising. Also, there is a considerable body of experimental work suggesting that more complex EEG paradigms may one day be used to assess changes in brain function after injury (discriminating

functions based on patterns of coherence, phase, and amplitude) [24]. A major limitation of this study was that EEG monitoring was not performed immediately during, and more importantly after CPB to detect possible post perfusion seizures, which have strongly associated with long-term neurological sequelae [14].

Appendix

Fig. 1. Pathological EEG recordings. **a)** Focal slowing in right temporal occipital lead, **b)** Generalised slowing, **c)** Epileptiform discharges (Spikes-and-wave complexes).

Authors' contributions

Sascha Meyer, Mohammed Ghiath Shamdeen, Ludwig Gortner, and Hashim Abdul-Khaliq were responsible for the study design, data analysis and writing of the manuscript.

Mohammed Shatat and Sven Gottschling were responsible for data acquisition and data analysis.

Hans-Joachim Schäfers was responsible for patient treatment, and writing of the manuscript.

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