

Awareness detection during Caesarean section under general anaesthesia using EEG spectrum analysis

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This study examined the relationship between the EEG (spectral edge frequency 90 – SEF90) and the occurrence of awareness defined for the purpose of this study as responsiveness to verbal commands. Fifty women undergoing general anaesthesia for elective Caesarean section were examined. Responsiveness to verbal commands was detected every minute in the period from the induction of anaesthesia to the delivery of the newborn using the Tunstall isolated forearm technique and correlated with the SEF90 value. The patients were assigned by a randomized code to receive either thiopentone (4 mg · kg⁻¹) or ketamine (1 mg · kg⁻¹) for induction of anaesthesia. Before the administration of succinylcholine a tourniquet was applied to the free arm, and inflated to 200 mmHg, to maintain motor function to one arm. The EEG recordings started five minutes before induction and were recorded throughout anaesthesia. The incidence of responsiveness to verbal commands was lower in the ketamine group (24%) where the average SEF90 was 12.0 ± 3 Hz, than in the thiopentone group (52%), where the average SEF90 was 18.09 ± 3 Hz (P = 0.01). The results suggest that SEF values of ≤8.6 Hz were sufficient to avoid responsiveness to verbal commands.

Cette étude évalue la relation entre l'analyse de fréquence spectrale (spectral edge frequency 90 – SEF90) sur l'EEG et l'éveil intra-opératoire défini dans cette étude comme une réponse à un ordre verbal. L'étude inclut 50 parturientes opérées sous anesthésie générale pour une césarienne élective. Nous avons

Key words

ANAESTHESIA: obstetrical, Caesarean section;
COMPLICATIONS: awareness;
MONITORING: EEG.

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Accepted for publication 1st January, 1995.

décelé les réponses à un ordre verbal à chaque minute en corrélation avec les valeurs du SEF90 pendant l'induction jusqu'à la naissance, en utilisant sur l'avant-bras la technique de Tunstall du garot isolant. Les patientes ont été réparties au hasard pour recevoir soit du thiopentone (4 mg · kg⁻¹) soit de la kétamine (1 mg · kg⁻¹) pour l'induction. Avant l'administration intraveineuse de succinylcholine, un garot isolant a été appliqué sur l'avant-bras et gonflé à 200 mmHg pour conserver l'activité motrice de l'avant-bras. L'EEG a été enregistré 5 min avant l'induction et pendant l'anesthésie. L'incidence des réponses à des ordres verbaux a été inférieure dans le groupe kétamine (24%) (SEF90 moyenne 12,0 ± 3 Hz) comparativement au groupe thiopentone (52%) (SEF90 moyenne 18,09 ± 3). Ces résultats suggèrent qu'une valeur de SEF inférieure à 8.6 Hz suffit pour prévenir la réponse aux ordres verbaux.

Awareness is the unintentional regaining of consciousness during presumed general anaesthesia and it has been recognized increasingly since the routine use of neuromuscular relaxants.¹ It can be a terrifying experience, representing a human and a medico-legal problem.²⁻⁴

Although the brain is the major target organ of anaesthetic drugs, ironically this organ system has been largely ignored in routine monitoring during anaesthesia and major surgery. The complexity of the equipment and the difficulty of reading an unprocessed EEG tracing has limited its use in the operating room.⁵

During the past decade, as a result of advances in computer-processed EEG analyzers, routine EEG monitoring in the operation room is becoming more common; the information obtained from the EEG being converted into a simplified form for the clinician.

The most widely used technique to process the EEG is power-spectrum analysis, which uses a computer to perform a Fourier transformation. In an attempt to simplify the description of the EEG, a number of descriptive variables has been derived from the power-spectrum analysis and they have been suggested as indicators of anaesthetic depth.^{6,7} One of the most commonly used is

the spectral edge frequency (SEF) which represents the highest frequency of the EEG.⁸ The SEF90 is the frequency below which 90% of the total brain power is contained.

Awareness during Caesarean section is a recognized problem with general anaesthesia.¹

Tunstall's technique for monitoring awareness during Caesarean section relies on isolation of the forearm from the effects of the neuromuscular blockade by occlusion of the circulation with a pneumatic tourniquet inflated before injection of the muscle relaxant. Movement of the hand in response to message is then monitored.³

This study was designed to investigate the correlation between responsiveness to verbal commands and simultaneously recorded SEF90 values.

Methods

Fifty women (ASA class I) 19–39 yr of age, undergoing elective Caesarean section with general anaesthesia were assigned by a randomized code to receive either thiopentone or ketamine for induction of anaesthesia.

The investigation was approved by the Institution Ethics Committee and all patients gave informed consent.

Preoperatively, all patients received 30 ml, 0.3 M sodium citrate *po*. In the operating room the patients were positioned on the operating table in a left lateral tilt of approximately 15°. Oxygen, 100%, was administered by mask for five minutes. Three minutes before anaesthetic induction d-tubocurarine (3 mg) *iv* was given.

Anaesthesia was induced according to the drug assignment with either thiopentone (4 mg · kg⁻¹) or ketamine (1 mg · kg⁻¹). When the patient lost consciousness, succinylcholine (1.5 mg · kg⁻¹) was given. Cricoid pressure was maintained until after the trachea has been intubated. Following intubation the lungs were ventilated with 50% nitrous oxide and 50% oxygen. End-tidal concentration of halothane was maintained at 0.5 MAC, measured by an infrared spectrophotometer (Datex-Ultima).

To assess intraoperative awareness a tourniquet was applied to the free arm, and was inflated to 200 mmHg before the administration of the succinylcholine to maintain motor function of one arm.

During the induction-to-delivery interval (I–D interval) the anaesthetist instructed the patient via headphones, once every minute, to raise her free hand.

After delivery, fentanyl, 2–3 µg · kg⁻¹ *iv*, was administered, the FiO₂ was reduced to 0.3, halothane was stopped, and the tourniquet was deflated. Before deflating the tourniquet, maintenance of motor function in the isolated forearm was confirmed by train-of-four using a peripheral nerve stimulator.

On arrival in the recovery room, all patients in the ketamine group received diazepam, 0.15 mg · kg⁻¹ *iv*, to

prevent postoperative dreams and other unpleasant emergence reactions.

The patients were studied using the Cerebrotrac 2500*EEG monitor to monitor and correlate their responsiveness to verbal commands with the behaviour of SEF90. The Cerebrotrac receives two channels of real-time EEG signals from the patient and converts the EEG waveform from the time domain to the frequency domain using the Fast Fourier Transform (FFT). The Cerebrotrac 2500 performs FFT using two-second EEG epochs. The band-width for recording was 0–30 Hz.

Five electrodes were placed in a bilateral frontomastoid array and electrode impedance was <20000 ohms. The EEG recordings were started five minutes before induction, recorded throughout anaesthesia and saved on disk.

The patients were interviewed approximately 24 hr after surgery to assess recall.

Apgar scores were assigned by a paediatrician.

Statistical analysis

The time course EEG changes between the groups and the values preceding and immediately following each incidence of responsiveness were compared with repeated measurements ANOVA followed by Newman-Keuls multiple comparisons procedure. Student's *t* test was used to compare the averages of the SEF90 values between the thiopentone and ketamine groups separately for those patients with responsiveness to verbal commands and for those without. Fisher's exact test was used to evaluate the SEF90 value indicative of no awareness. A *P* value <0.05 was considered to be statistically significant. All values are given as the mean ± SD.

Results

The groups were similar with respect to age, weight and induction to delivery interval (Table I).

In the thiopentone group, 13 of 25 patients (52%), moved their hands in response to the anaesthetist's instruction, before delivery. The pre-delivery movements in response to command occurred at an average SEF90 value of 18.09 ± 3.1 Hz. In the ketamine group, five of 25 patients (24%) moved their hands in response to command before delivery at an average SEF90 of 12.0 ± 3 Hz. Figure 1 depicts the SEF90 changes as a function of time in patients with responsiveness to verbal command, in both groups (thiopentone and ketamine).

Twelve patients in the thiopentone group did not move their hands in response to instruction. The average SEF90 in these patients was 13.5 Hz. Twenty patients in the ketamine group did not move their hands in response

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TABLE I Characteristics of the study groups

	Thiopentone (n = 25)	Ketamine (n = 25)
Age (yr)	26.2 ± 5	25.5 ± 5
Weight (kg)	72.8 ± 7	72.0 ± 9
Induction to delivery interval (min)	9.4 ± 1	9.0 ± 1

Values are mean ± SD.

to the anaesthetist's instruction. The average SEF90 in these patients was 9.4 ± 1 Hz. Figure 2 depicts the SEF90 changes as a function of time in patients without responsiveness to verbal command, in both groups (thiopentone and ketamine).

The incidence of awareness was lower in those patients in whom anaesthesia was induced with ketamine as compared with thiopentone ($P = 0.08$).

In the thiopentone group there were three spontaneous movements indicating probable light anaesthesia at an average SEF90 value of 17.6 ± 5 Hz (Figure 3).

Fisher's exact test suggested that SEF90 value of 8.6 Hz was related to unresponsiveness to verbal command ($P = 0.06$).

There was a difference between the SEF90 values at the time of responsiveness to verbal commands (mean 16.5 ± 5 Hz) compared with SEF90 values immediately following each incidence of responsiveness (mean 19.3 ± 5 Hz; $P = 0.003$). There was no difference between the SEF90 values immediately preceding (mean 17.2 ± 5 Hz) and at the time of responsiveness to verbal commands (Figure 4).

None of the patients recalled anything of the surgery.

With respect to the newborn, no difference could be shown in the Apgar scores of the two groups (Table II).

Discussion

This study used the isolated forearm technique to detect awareness during elective Caesarean section and examined the relationship between the EEG (SEF90) and the occurrence of awareness defined as responsiveness to verbal commands. The results show that if the SEF90 values recorded during the I-D interval were ≤ 8.6 Hz there was no response to verbal commands. The SEF90 values ≥ 8.6 Hz at any given moment did not necessarily predict awareness at that time.

Changes in the SEF have been shown to correlate in a predictive fashion with serum concentrations of opioids⁹ and barbiturates.¹⁰ Rampil and Matteo⁸ demonstrated that haemodynamic responses to tracheal intubation could be prevented during a thiopentone-lidocaine-fentanyl-

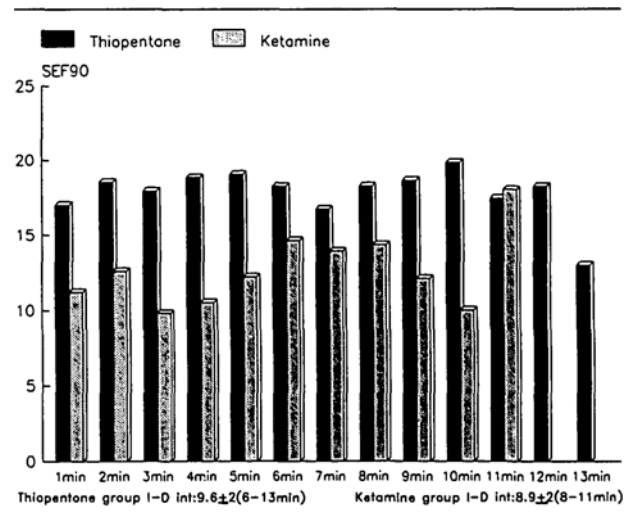


FIGURE 1 Movements in response to command: The time course changes of the SEF90.

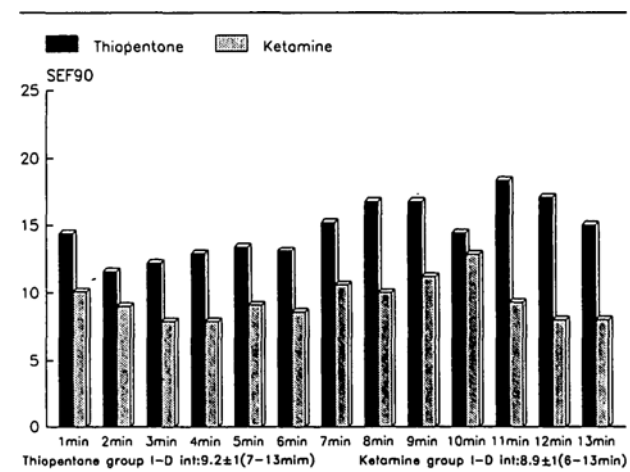


FIGURE 2 No movements: The time course changes of the SEF90.

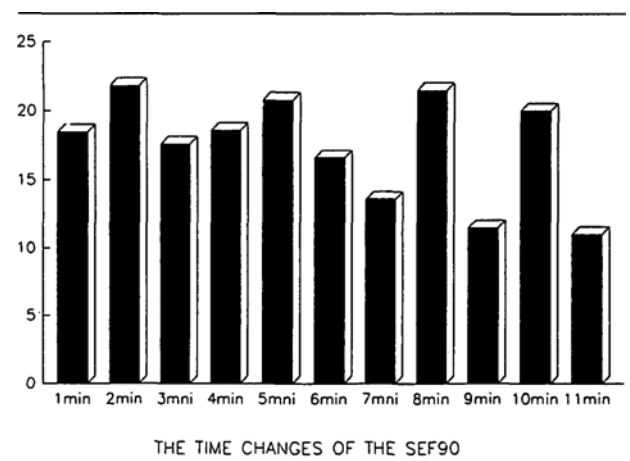


FIGURE 3 Thiopentone group: Spontaneous movements.

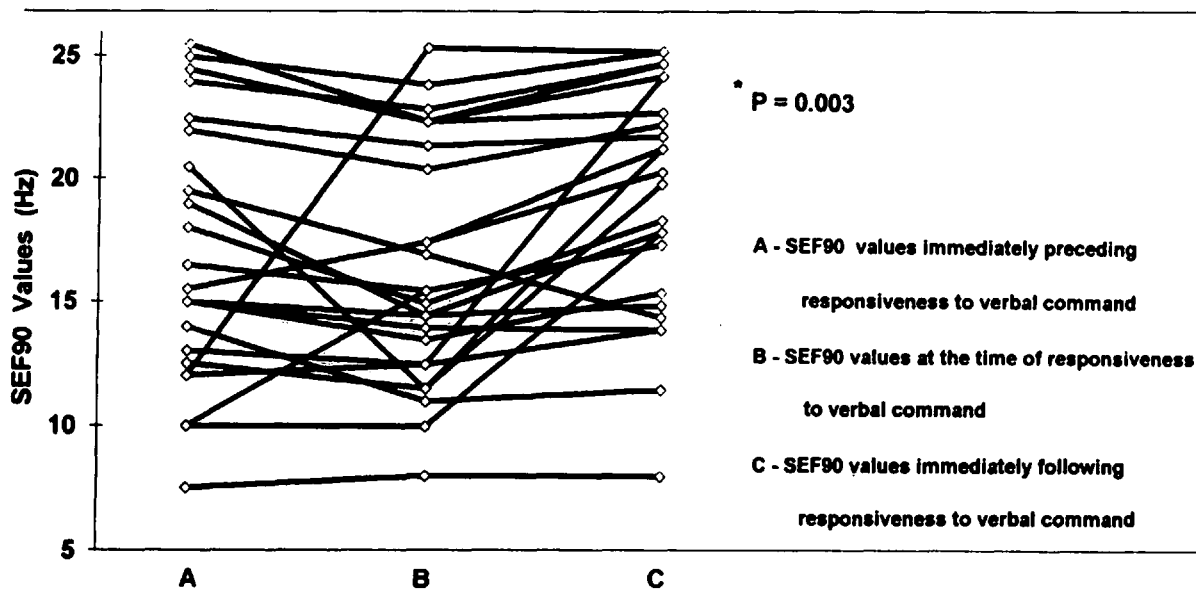


FIGURE 4 Comparison between the SEF90 values immediately preceding, at and immediately following responsiveness to verbal commands.

TABLE II Apgar scores

	Thiopentone (n = 25)	Ketamine (n = 25)
Apgar score >7 (n)		
- 1 min	21	22
- 5 min	25	25

droperidol anaesthetic sequence if the SEF was <14 Hz. In the Stoeker and Schwilden series it was shown that median values <5 Hz reduced the likelihood of intraoperative awareness.¹¹ In this study SEF90 values <8.6 Hz were associated with lack of responsiveness to verbal commands during the I-D interval and therefore predictive of non-awareness. Comparing our study with these studies revealed that there was a correlation between the computerized EEG descriptors (SEF, median power frequency) and awareness. These findings require further investigation in larger series of comparative studies of frontalis muscle activity, EEG processed in various ways, auditory-evoked potentials and isolated forearm technique in order to resolve some of the questions concerning awareness.

Some authors believe that SEF has limitations, being a poor indicator of anaesthetic depth.^{12,13} Arden and Holley¹² found that, although the change in SEF mirrors at an increasing anaesthetic concentration, there is a considerable lag in the recovery of SEF when anaesthetic levels are falling. White and Boyle¹³ found no consistent relationship between SEF and haemodynamic responsive-

ness to surgical stimulation in patients undergoing general anaesthesia with propofol and nitrous oxide.

There are still no guidelines for EEG use during routine general anaesthesia but the simplicity of this technique may in the future permit the routine use of intraoperative EEG monitoring.

This study also confirms that intraoperative maternal awareness during Caesarean section is lower after induction of anaesthesia with ketamine than after thiopentone.¹⁴⁻¹⁶ Ketamine, in doses of $1 \text{ mg} \cdot \text{kg}^{-1}$ may be used instead of thiopentone as an induction agent in Caesarean section, with no difference in neonatal outcome compared with thiopentone.¹⁴ However, ketamine can produce unpleasant psychological reactions during awakening from anaesthesia, called emergence phenomena.¹⁷ The benzodiazepines seem to be the most effective drugs in preventing these phenomena.¹⁷ In this study, after arrival in the recovery room, patients received diazepam which influenced recall. The standard method of induction of anaesthesia with thiopentone offers the advantage of less abnormalities of mental status immediately after anaesthesia.¹⁶

In conclusion, we found that SEF90 values of ≤ 8.6 Hz were sufficient to avoid responsiveness to verbal commands. We also found that ketamine induction for Caesarean section in doses of $1 \text{ mg} \cdot \text{kg}^{-1}$ had a lower incidence of intraoperative awareness than with thiopentone induction ($4 \text{ mg} \cdot \text{kg}^{-1}$). This study demonstrates continuous monitoring of the EEG during general anaesthesia, especially during Caesarean section, using computerized analysis and a graphic display appears to provide a sensitive method of recognizing awareness.

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