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Spectral Analysis of the EEG-signal Registered during Anaesthesia Induced by Propofol and Maintained by Fluorinated Inhalation Anaesthetics

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The aim of this study was to identify the effects of different volatile anaesthetics (isoflurane, desflurane or sevoflurane) on the spectro-temporal pattern of EEG during all of the stages of anaesthesia recorded at the frontal derivations in 64 adult patients. The relative powers of EEG for delta, theta, alpha and beta frequency bands as well as the characteristics of their time evolution and their relationships with the concentrations of anaesthetics were used as the EEG spectra indices. The time evolutions of the individual wave powers in 75% of patients were similar for all the anaesthetics used in this study at the same method of administration. Well correlated biphasic changes in the slow and fast wave powers emerged after propofol induction as well as in association with the volatile anaesthetics action. Wave powers as well as their relationships with the anaesthetic concentrations were not hampered by the variability across the patients and anaesthetics used in this study. Comparing the branches of increasing and decreasing concentration, the hysteresis phenomenon, i.e. systematic decrease or increase of each wave power, was observed at the end of anaesthesia for each of the volatile anaesthetics. A rapid increase of sevoflurane concentration at the initial phase of anaesthesia caused more effective attenuation of beta waves than in the case of gradual anaesthetic administration but it happened at the cost of the intensification of delta waves.

Keywords: EEG-signal, volatile anaesthesia, fluorinated inhalation anaesthetics, isoflurane, desflurane, sevoflurane, spectral analysis, biphasic effect, hysteresis

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1. Introduction

Evolution of spectro-temporal pattern of EEG during anaesthesia was studied previously [1–4] and it was found that increasing concentration of anaesthetics produced decreasing of fast and increasing of slow wave component in the EEG signal. These studies were focused mainly on the problem of transition from consciousness to unconsciousness. The quantitative analysis of EEG for all of the stages of anaesthesia as well as for different methods of agent administration was not performed. Moreover, the problem of reproducibility of analyzed indices was not solved using the representative number of patients and anaesthetics.

Therefore in this study we assessed the indices of EEG in all the stages of anaesthesia as well as the reproducibility of obtained results with respect to the patient and anaesthetic related variability was analyzed also. The study was performed using EEG recorded in patients anasthetised with isoflurane (11 patients), desflurane (18 patients) and sevoflurane (35 patients) anaesthetics. The relative powers in delta (1–3 Hz), theta (4–7 Hz), alpha (8–13 Hz) and beta (14–25 Hz) bands of the EEG signal as well as their group means and standard deviations were determined. The temporal evolution of these indices as well as their relationships with the individual anaesthetic concentrations were identified and compared.

2. Materials and Methods

2.1. Patients

The data were taken from 64 adult patients of both genders that underwent orthopaedic surgery under general anaesthesia, categorized as class I (normal, healthy patients) and II (patients with mild systemic disease) according to the American Society of Anaesthesiologists (ASA) scale. The patients were anaesthetised with volatile agents chosen randomly: isoflurane (11 patients), sevoflurane (35 patients) and desflurane (18 patients). The patients with history of allergic reactions to drugs used in the study, the patients with epilepsy and with other previously diagnosed neurological deficits and/or psychiatric disorders, as well as the patients receiving neuropsychiatric medication and addicted to any psychoactive substances were excluded from the study. The study was approved by the Ethical Committee of the Medical University of Silesia and written informed consent was obtained from all of the patients involved.

2.2. Experimental Procedure

In the morning of the day of surgery the patients did not receive any premedication to avoid its influence on the EEG patterns. In the operating room an i.v. cannula was inserted into the large forearm vein and continuous standard monitoring was applied. The monitoring included heart bioelectric activity (ECG), heart rate (HR), non-invasive systemic arterial pressure, respiratory rate, haemoglobin oxygen saturation, and end-tidal concentrations of the volatile anaesthetic agents, oxygen and carbon dioxide. Oxygen saturation was measured by pulse oxymetry and maintained above 95% during the study. In order to avoid opioid and nitrous oxide effect on central nervous system, analgesia during surgery was achieved by an epidural catheter placed in the lumbar space, via which patients received 20 ml of 0.5% bupivacaine (Marcaine, Astra-Zeneca). In all the patients, anaesthesia was induced intravenously with 2–2.5 mg kg^{-1} of propofol (Diprivan, Astra-Zeneca). Before anaesthesia induction oxygen was administered by facemask. Each patient received a muscle-relaxant factor 0.08–0.10 mg kg^{-1} of vecuronium (Norcuron, Organon) and 3 min later laryngeal mask was inserted. The lungs were mechanically ventilated to obtain the end-tidal carbon dioxide concentration of 35–37 mmHg. The administration of volatile anaesthetic was started after a waiting time needed to eliminate the effect of intravenous induction. The mean waiting time duration was about 8 minutes (from 1 to 23 minutes).

The anaesthetic concentration was measured every 10 seconds in Minimal Alveolar Concentration (MAC) units. MAC is defined as the partial pressure of volatile anaesthetic inhibiting movement reaction for noxious stimulation in 50% of anaesthetized patients.

Two different methods of volatile anaesthetic administration were applied. In the first method the anaesthetic concentration was increased gradually by 0.2 MAC every 5 minutes up to the maximal concentration which ranged in the individual patients from 1.4 to 2.0 MAC. Then the concentration of anaesthetic agent was subsequently decreased by 0.2 MAC every 5 minutes until the end of surgery, return of consciousness and the laryngeal mask removal. In the second method the maximal concentration value was elicited at the initial phase of anaesthesia and then it was decreased slowly. Anaesthesia with first method was applied in all patients anaesthetized with either desflurane or isoflurane and in 7 patients anaesthetized with sevoflurane whereas second method was applied in 21 patients anaesthetized with sevoflurane (Table 1).

No more neuromuscular blocking agents were given intraoperatively. Emergence from anaesthesia was assessed by measuring the times to spontaneous opening of eyes and stating the name. Finally, all the patients were visited in the post-anaesthesia care unit on first and third day after operation and interviewed about intraoperative recall.

Table 1. Number of patients and applied method of anaesthetic administration.

Anaesthetic administration method	Number of patients isoflurane	Number of patients desflurane	Number of patients sevoflurane
1st	11	18	7
2nd	–	–	28

2.3. EEG Registration

The EEG signal was registered from the electrodes fastened on a self-adhesive band, placed at the forehead with sampling frequency 400 Hz using Datex-Ohmeda S/E (GE Healthcare) monitoring system. The registrations were analyzed off line.

2.4. Data Analysis

To assess the effects of anaesthetics on the spectro-temporal pattern of EEG signal the values of individual wave contributions defined as the relative powers of the EEG calculated for delta (1–3 Hz), theta (4–7 Hz), alpha (8–13 Hz) and beta (14–25 Hz) waves frequency bands [5,6] as well as their time evolution and their relationships with the concentrations of individual anaesthetics were used. Both the relationships for the relative powers in the individual patients and the relationships for the group means of relative powers were used.

The spectral analysis was performed using MATLAB Signal Processing Toolbox. The procedure *specgram* was used to compute the windowed discrete-time Fourier transform of signal using sliding window. The sampling frequency 400 Hz and Hann window of one-second length overlapping by 200 points were used. The power spectral density was estimated as the squared magnitude of the discrete-time Fourier transform of the EEG-signal. Then the relative powers of EEG for individual frequency bands were calculated as power normalized to temporary total power of signal in the range of frequency from 1 to 25 Hz. The power of the signal in a given frequency band was calculated by integration procedure over frequencies. Because anaesthetic concentration was registered every 10 sec the relative power spectral densities for the individual waves were averaged over such window to obtain their relationships with the anaesthetic concentration.

Distributions of powers for the individual anaesthetics at the same concentration had not equal variances, so to compare their means the Kruskal-Wallis test was used. The differences in the means were considered significant if $p < 0.01$.

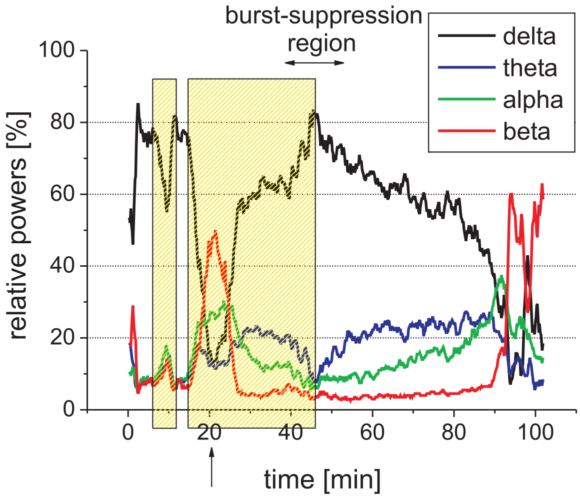
3. Results

3.1. Time Evolution of EEG Power

The time evolution of the EEG relative power in the frequency bands corresponding to delta, theta, alpha and beta waves during anaesthesia induced by propofol and maintained by the administration of volatile anaesthetic with gradually increasing concentration is exemplified in Fig.1.

Before the anaesthesia induction, the contribution of delta waves was distinctly larger compared to that of alpha, beta and theta waves. Administration of propofol evoked transient changes denoted by the first narrow bar in Fig. 1a, which lasted in the individual patients from 40 to 300 secs. These changes satisfied the criterion of biphasic effect, i.e. an initial increase of alpha and beta wave activities was followed by their decreases with a simultaneous increase of delta frequency activity. The amplitudes of changes were dose depended and ranged in the investigated patients from 10 to 60 % and from 15 to 65 % of the total power for beta and delta waves, respectively.

a)



b)

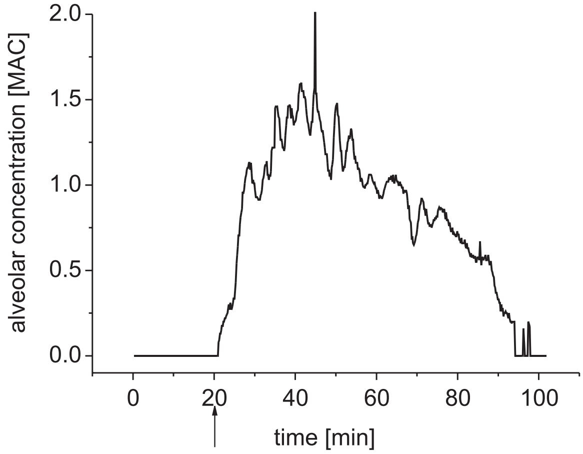


Fig. 1. Example of the EEG power time evolution and the anaesthetic concentration for patient id_35 under isoflurane anaesthesia: a) time evolution of the relative powers for delta, theta, alpha and beta waves smoothed by averaging adjacent six data points; yellow bars indicate biphasic effects, i.e. an initial increase followed by a decrease of high frequency activity with a simultaneous increase of low frequency activity; b) time evolution of anaesthetic concentration in the anaesthesia with concentration increased gradually to the maximum and then decreased again in the same manner. Arrow indicates the start of isoflurane anaesthesia

Similarly shaped but slow changes, denoted by the second wide bar in Fig. 1a, emerged before or just after the end of waiting time and lasted in the investigated patients from 5 to 50 minutes during the gradual increase of anaesthetic concentration. The slow effects were observed in 70% of the patients anaesthetized with either desflurane or isoflurane and in all the patients anaesthetized with sevoflurane administrated with gradually increasing concentration. On the other hand, in the patients anaesthetized with sevoflurane with rapidly increased concentration, this effect was observed only in 30% of the patients. In the remaining instances such effects were absent because the contribution of neither alpha nor beta waves manifested regular increases followed by their decreases. In the course of slow effects the alpha and beta wave contributions in the individual registrations were increased and reached their maximal values ranging from 15 to 65% and from 10 to 50% whereas their means were 33±10 and 25±11% of the total power, respectively. On the other hand contributions of the delta waves were decreased and reached their minimal values ranging from 9 to 39% with the mean value of 24±11% of the total power. Maximal and minimal contributions of the individual waves were observed at or after the end of waiting time.

Maximal contributions of the alpha and beta waves were not correlated ($p = 0.09$). Contrary, relationship between the minimal contribution of delta waves and sum of the maximal contributions of alpha and beta waves was statistically significant. The correlation coefficient and the slope of respective regression were –0.88 and –0.79 (Fig. 2a).

During progress of the slow effects the contributions of alpha and beta waves were decreased whereas those of delta waves were increased. The minimal values of alpha and beta wave contributions appearing at the end of the slow effects ranged from 3 to 25% and from 2 to 15% with means of 10±5 and 8±4%. Contributions of the delta waves reached their maximal values ranging from 35 to 85%, 56±13% of the total power. The minimal contributions of the alpha and beta waves were positively correlated with the correlation coefficient 0.51 and the slope of regression was 0.33. Similarly as the minimal contribution of the delta waves also the maximal contribution was negatively correlated with sum of the minimal contributions of the alpha and beta waves. The correlation coefficient and the slope of respective regression were –0.67 and –1.09 (Fig. 2b).

It was shown that also differences between the maximal and minimal wave contributions were well correlated. Relationship between difference in the delta wave contributions and difference in sum of the alpha and beta wave contributions was significant with the correlation coefficient 0.75 and the slope 0.90 (Fig. 2c). On the other hand the symmetric relationships for the theta waves were non significant ($0.25 < p < 0.85$). Therefore this analysis showed that slow changes satisfied the general criterion of biphasic effect similarly as the short ones observed after propofol induction.

First half of the burst-suppression region in some patients was characterized by rapid increase of the delta wave contribution with simultaneous decrease of the theta

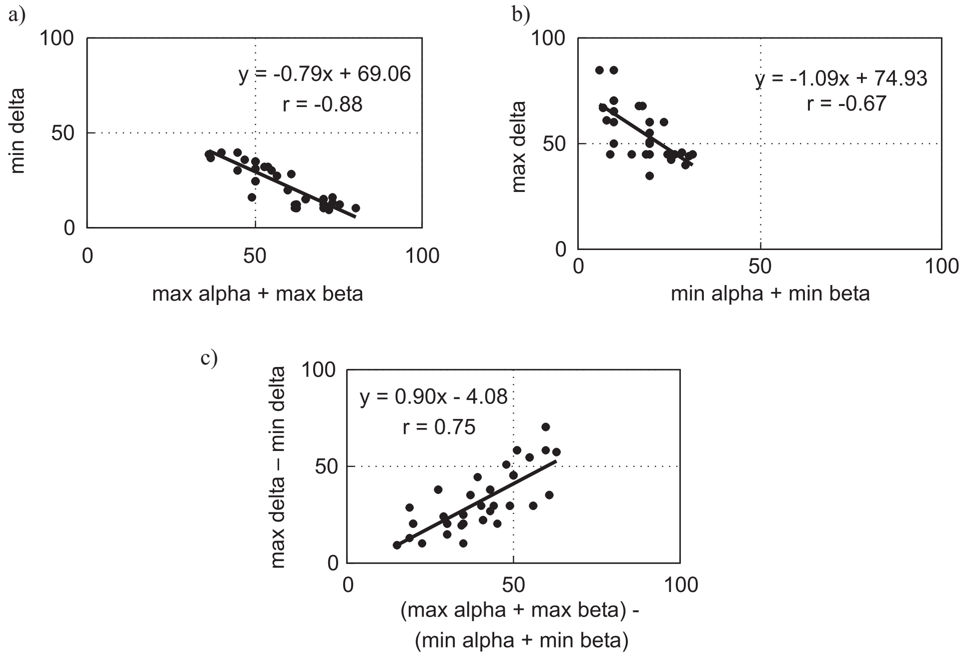


Fig. 2. The relationships between the slow and fast wave powers during slow biphasic effect in subgroup of the patients in which this effect was observed: a) between minimal value of the delta wave power and sum of maximal powers of the alpha and beta waves; b) between maximal value of the delta wave power and sum of minimal powers of the alpha and beta waves; c) between change in power of the delta waves and simultaneous change in summary powers of the alpha and beta waves during the biphasic effect

wave contribution and sometimes accompanied by decrease of the fast waves also. An example of such behaviour was showed in Fig. 1. The maximal contribution of delta waves at the maximal anaesthetic concentration approached 90% of the total power while the contributions of the remaining waves were small (about 3% of the total power). The similar pattern appeared in 20 patients, but more frequently in the patients under isoflurane (82%; $n_{iso} = 9$) than under desflurane (44%; $n_{des} = 8$) or sevoflurane (8%; $n_{sevo} = 3$). During the anaesthetic concentration decrease the contributions of all waves returned to the initial values and the sharp growth in the beta waves contribution at the end of the registration indicated the moment of the patient awaking. It showed that the pattern of contributions of the slow and fast waves evoked by the alterations in anaesthetic concentration during all the stages of anaesthesia was more complex than simple biphasic one.

An example of the individual wave contributions during the anaesthesia, in which the maximal concentration of sevoflurane was elicited at the initial phase of anaesthesia and then it was decreased slowly, is presented in Fig 3. A general feature of the EEG power associated with this pattern of sevoflurane concentration was lack of distinct slow biphasic effect appearing in the initial stage of anaesthesia. Slow biphasic effects present in patients with slow increase of anaesthetic concentration increase were damped and shortened in patients with rapid anaesthetic concentration increase (first short bar in Fig. 3). Moreover in approximately 30% of patients slow biphasic like effects with less distinct alterations of individual wave contributions appeared during the concentration decrease (second bar in Fig. 3).

a)

b)

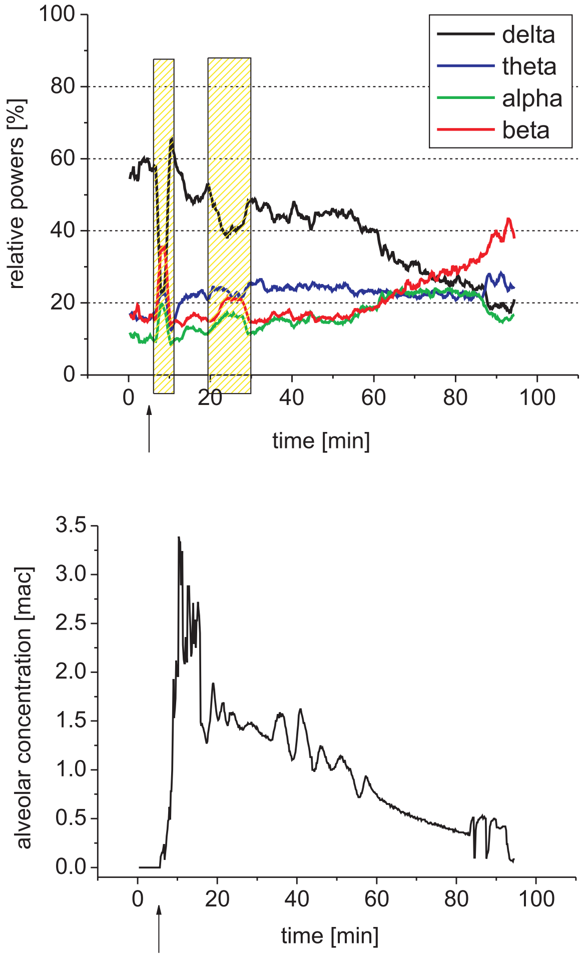


Fig. 3. An example of the time evolution of the relative powers of delta, theta, alpha and beta waves and of the anaesthetic concentration for patient id_22 under sevoflurane anaesthesia: a) time evolution of the relative powers of delta, theta, alpha and beta waves smoothed by averaging adjacent six data points; yellow bars indicate the biphasic effects, i.e. an initial increase followed by a decrease of high frequency activity with a simultaneous increase of low frequency activity; b) time evolution of anaesthetic concentration in the anaesthesia with maximal concentration value elicited at the initial phase of anaesthesia and then decreased gradually. Arrow indicates start of the sevoflurane anaesthesia

3.2. Relationships between the EEG Power and the Anaesthetic Concentration

Relationships between the relative powers of the individual waves averaged in the groups of patients anaesthetised with either isoflurane, desflurane or sevoflurane and the anaesthetic concentrations were calculated separately for increasing and decreasing concentrations. Relationships for alpha and theta waves' power manifested good similarity irrespectively of the agent (Fig. 4). On the other hand the powers of beta waves for sevoflurane concentration increasing from 0.2 to 0.8 MAC were distinctly larger compared to those observed in the remaining instances whereas those of delta waves were smaller. Statistically significant differences ($p < 0.01$) between the effects of individual anaesthetics not exceeding in the vast majority of instances 10% of the total power were found only for the concentrations lesser than 0.7 MAC (Fig. 4).

Only the alpha waves' power manifested a weak maximum of approximately 30% of the total power for the concentrations ranging from 0.5 to 0.7 MAC and were 20

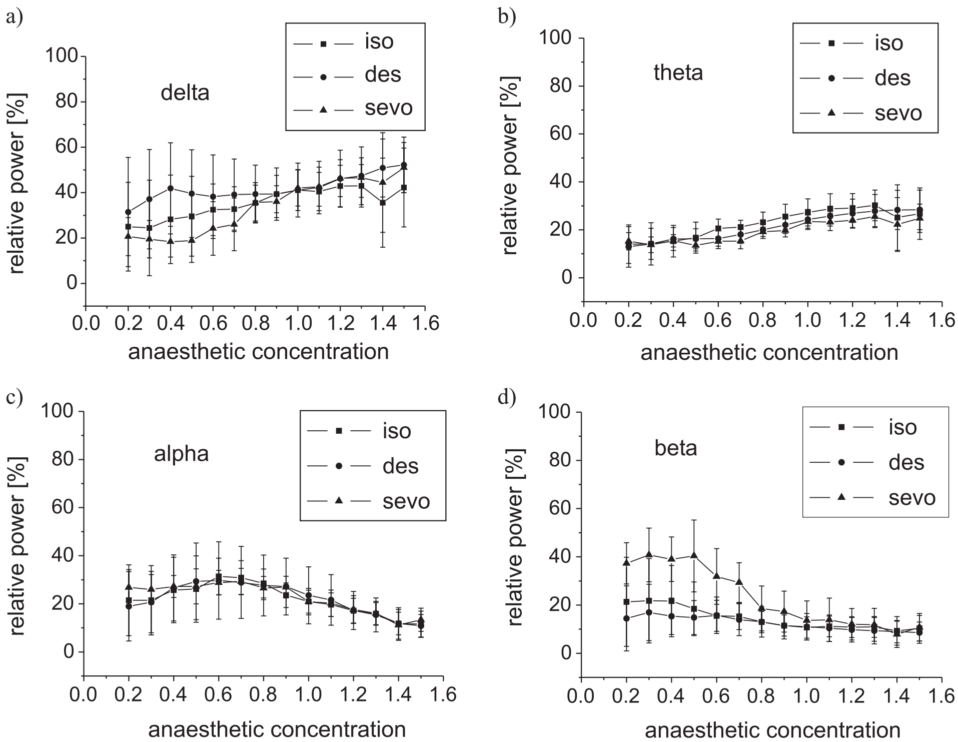


Fig. 4. Relationships between the relative powers of the EEG signal and the anaesthetic concentrations (branch of increasing concentration) for patients anaesthetised with isoflurane, desflurane or sevoflurane. The relationships were illustrated separately for the individual waves: a) delta, b) theta, c) alpha, d) beta. Every point on the plot corresponds to the mean power for the corresponding anaesthetic concentration in the group of patients. Error bars indicate standard deviations of relative powers for the individual anaesthetic concentrations

and 10% of the total power at the lowest and highest concentration, respectively. On the other hand power of the remaining wave changed monotonically over the whole range of concentrations. Power of the beta waves decreased with each anaesthetic concentration increase and for the concentrations greater than 1.0 reached constant values equal approximately 10% of the total power. Power of the delta waves increased approximately to 50% of the total power at the concentration equal 1.5. Power of the theta waves increased slower than the delta ones and for the concentrations bigger than 1.0 being almost constant reached approximately 30 % of the total power (Fig. 4).

The standard deviations of relative powers for the individual anaesthetics were largest for the delta and beta waves for the concentrations lesser than 0.6 (from 15 to 22 % of the total power). On the other hand standard deviations for the alpha and theta waves were small in the whole range of concentration values (from 4 to 14% of the total power). The smallest standard deviations (from 2 to 7% of the total power) were found for fast waves for the concentrations greater than 1.0 (Fig. 4).

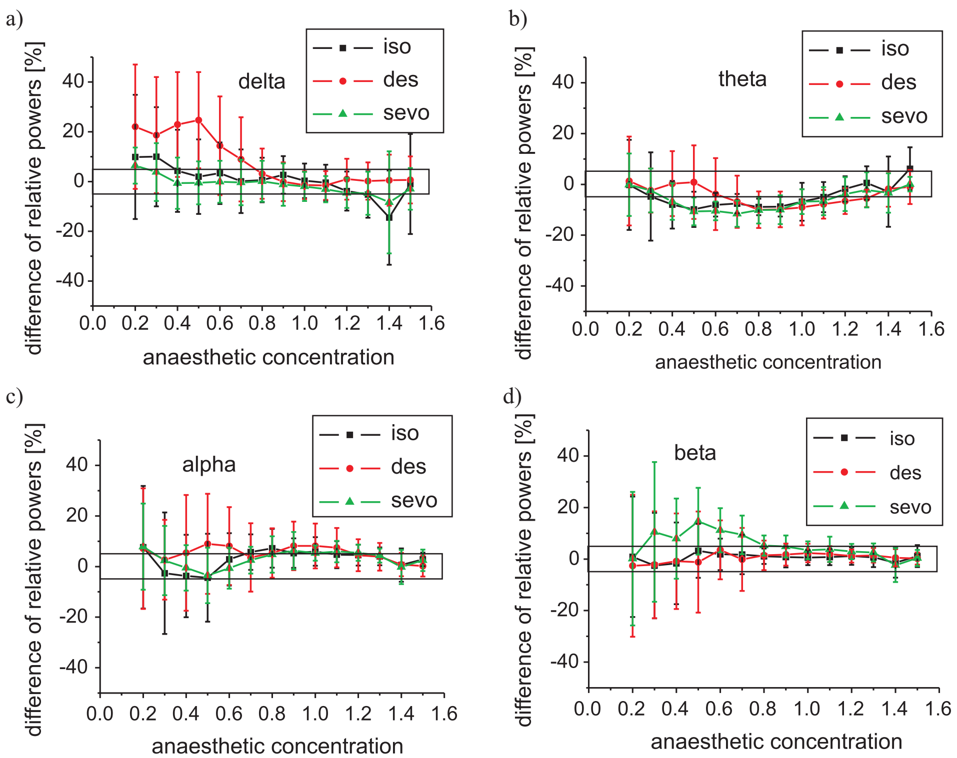


Fig. 5. Relationships between difference between the relative powers in increasing and decreasing branches of concentration and the anaesthetic concentrations for the patients anaesthetised with isoflurane, desflurane or sevoflurane. The relationships were illustrated separately for the individual waves: a) delta, b) theta, c) alpha, d) beta. Every point on the plot corresponds to the mean difference between power for the corresponding anaesthetic concentration in the group of patients. Error bars indicate standard deviations of the difference

Analysis of the EEG spectro-temporal patterns performed for increasing and decreasing of the anaesthetic concentration showed different sensitivity of the individual wave contributions to time evolution of the anaesthetic concentration. A very weak but systematic hysteresis phenomenon was observed. At the end of anaesthesia power of the delta waves was reduced in the desflurane anaesthesia what was manifested by positive difference greater than 5% between branch of increasing and decreasing concentration. On the other hand power of the beta waves was smaller in the sevoflurane anaesthesia. Power of the alpha waves was slightly smaller for isoflurane and sevoflurane in range from 0.7 to 1.3 MAC and for desflurane in range from 0.4 to 1.3 MAC. On the other hand power of the theta waves was slightly larger for isoflurane and sevoflurane in range from 0.4 to 1.0 MAC and for desflurane in range from 0.7 to 1.0 (Fig. 5).

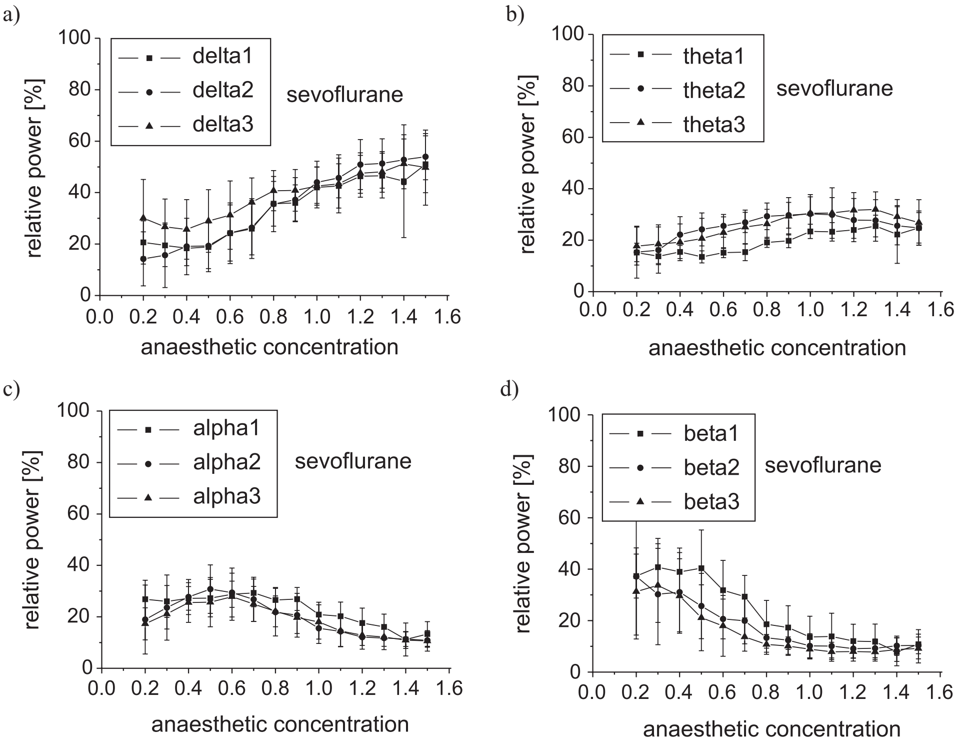


Fig. 6. Comparison of the relationships between the relative powers of the individual waves and the sevoflurane concentration for three patterns of concentration change. The relationships were illustrated separately for the individual waves: a) delta, b) theta, c) alpha, d) beta. Every point on the plot corresponds to the mean power for the corresponding anaesthetic concentration in the group of patients. Error bars indicate standard deviations of the relative powers. Denotations of concentration patterns: 1 – gradual increase of concentration; 2 – gradual decrease of concentration after the maximal concentration was elicited during gradual increase; 3 – gradual decrease after the maximal concentration was elicited rapidly at the initial phase of anaesthesia

Both methods of sevoflurane administration produced differences in wave powers most substantial in the range between 0.2 and 0.8 MAC (Fig. 6). In the method with gradual increase followed by decrease of concentration the concentrations increasing from 0.2 to 0.8 MAC produced beta waves with power larger compared to those produced by the decreases of the concentration in both methods. On the other hand power of delta waves in the former method both during increase and decrease of concentration was smaller compared to that observed in the method with rapid increase of concentration for concentrations decreasing from 0.8 to 0.2. Therefore it may be suggested that the method of sevoflurane administration with gradual increase and decrease of concentration was less stressful for patient.

4. Discussion and Conclusions

The obtained results are generally consistent with those of our previous preliminary studies [7, 8] performed on data registered in a small group of patients with the use of qualitative assessment of the EEG spectrum only. The present study performed on the representative group of patients with the use of quantitative methods of the EEG analysis offered the possibility to generalize the obtained results.

It was shown that time evolution of the individual wave contributions manifested systematic features similar for all the anaesthetics used. During the anaesthesia induction they demonstrated short biphasic effects evoked by propofol administration. Before or just after end of the waiting time power of the alpha and beta waves demonstrated spontaneous increase followed by their decrease. On the other hand power of the delta waves manifested opposite changes well correlated with those of fast waves. These alteration were much slower than those evoked by propofol. They could last until the burst suppression region observed at maximal anaesthetic concentration and also satisfied criterion of the biphasic EEG effect. These slow biphasic effects were observed in 70% of patients anaesthetized with either desflurane or isoflurane and in all the patients anaesthetized with sevoflurane during the anaesthesia with regular increase of anaesthetic concentration followed by concentration decrease. On the other hand in the patients anaesthetized with selvoflurane with rapid increase of concentration followed by slow concentration decrease the biphasic effects initiated before the anaesthetic administration were damped during the anaesthetic concentration increase. Nevertheless in 30% of patients small the slow biphasic effects could be observed during anaesthesia progression at concentrations ranging from 1.5 to 2.0.

The next characteristic feature of the evolution of individual wave contributions was the increase of contribution of the delta waves accompanied by symmetrical decrease of contribution of the theta waves in region of the burst suppression. Therefore in the middle of the burst suppression region at the highest anaesthetic concentration contribution of the delta waves was dominating and approached

90% of the signal total power. Immediately after the burst suppression offset contributions of the delta and theta waves returned to the values from before the burst suppression onset and manifested systematic decrease following the decrease of anaesthetic concentration. On the other hand contribution of the alpha waves was increased slowly after burst suppression offset whereas that of the beta waves was increased rapidly as late as at the end of anaesthesia state when the anaesthetic concentration was the smallest.

The analysis of relationships between the individual wave contributions and the concentration showed that the gradual concentration increases irrespectively of the kind of anaesthetic elicited the decrease of the fast waves, beta and alpha, contributions accompanied by simultaneous increase of the slow ones, delta and theta, contributions. Nevertheless the contribution of beta waves differed from the contribution of alpha waves in that the former one was almost constant for the concentrations greater than 1.0 and in the whole range of concentrations it was smaller. On the other hand contribution of the alpha waves manifested weak maximum at the concentrations from 0.5 to 0.7 MAC. Contribution of the theta waves was almost constant for the concentrations greater than 1.0 and was lesser if compared to that of the delta one. For concentration equal 1.6 the contributions of the alpha and beta waves decreased to about 10%, whereas those of the theta and delta waves reached about 30 and 50% of the total power, respectively.

The quantitative analysis of EEG did not demonstrate substantial difference between the effects of isoflurane, desflurane, and sevoflurane on the individual wave contributions for the agent concentrations larger than 0.7. However, for the concentrations smaller than 0.7 the maximal difference between the relative powers of the delta and beta waves obtained for the individual anaesthetics approached 10% of the total power. The smallest standard deviations independently of the kind of anaesthetic, for all groups of patients, were observed for the concentrations greater than 1.0, when in 50% of anaesthetized patients the movement reaction for noxious stimulation was not observed.

Comparing of branches of increasing and decreasing concentration showed the hysteresis phenomenon. It suggested that at beginning of the sevoflurane anaesthesia the beta waves activity was highest and less sensitive to concentration increase compared to isoflurane and desflurane whereas at end of the anaesthesia the effects of individual anaesthetics were much more similar. On the other hand the delta and alpha waves irrespectively of the anaesthetic at end of the anaesthesia manifested smaller activities compared to those observed at the beginning.

It was shown that the effect of rapid increase of sevoflurane concentration at the anaesthesia beginning was mirrored by damped slow biphasic effects whereas slow biphasic like effects appeared during the concentration decrease. Moreover this method of anaesthetic administration in the whole range of concentrations evoked contribution of the delta waves smaller than in the method with gradual increase followed by decrease of concentration. On the other hand contributions of the alpha, beta and theta waves were less differentiated compared to the method with gradual concentration increase.

Quantitative characteristics of the spectro-temporal pattern of EEG during anaesthesia were studied previously in several studies [1–4, 7, 8]. Lloyd-Thomas et al. [1] found that increasing of concentration of isoflurane from 0.5 to 2.0% with step of 0.5% reduced fast and increased slow wave components in the spectrum of EEG registered from parietal regions. Similarly Kuizenga et al. [2] using analysis of amplitude in low and high frequency bands described progression of spectral characteristics in response to increasing of anaesthetic concentration during 10 minutes of anesthesia induction. A biphasic effect, i.e. an initial increase followed by a decrease of high frequency activity with a simultaneous increase of low frequency activity was observed for sevoflurane and propofol. Our results obtained for EEG registered from frontal derivations during the waiting period as well as during anaesthesia progression are consistent with this general rule. Moreover our results obtained using the relative EEG power contrary to those obtained by Kuizenga et al. [2] with analysis of the EEG amplitude did not showed for inter-subject variability limiting their applicability. Similarly as in the study of Lloyd-Thomas et al. [1] we found a relatively steady state characterized by constant ratios of beta and delta as well as of beta and theta wave relative powers for the concentrations larger than 1.0. Rundshagen et al. [9] using thiopental and fentanyl did not found any biphasic EEG response during induction reporting only reduced alpha and beta powers and an increase of delta power. In our study the biphasic effect appeared in the all registrations therefore it may be suggested that, in contrary to propofol, thiopental and fentanyl did not evoke a biphasic EEG response during induction. Koskinen et al. [3] provided a more detailed description of the spectro-temporal pattern progression using analysis of seven frequency bands. During induction of anaesthesia with propofol administrated at constant rate they found that the biphasic activity pattern shifted rather smoothly from high towards low frequencies in time. Thus, the occurrence of the biphasic activation was bandpass specific. However, the frequency progression pattern was examined only from start of the infusion to loss of obeying of verbal command. Similar frequency progression pattern was found by Kortelainen et al. [4] analyzing of EEG from the start of the propofol infusion to the onset of the burst-suppression pattern. Nevertheless the different method of EEG analysis these results are consistent with our data.

Our study showed that during anaesthesia induction propofol evoked dose dependent short biphasic effects whereas desflurane, isoflurane or sevoflurane used to maintain anaesthesia evoked similarly shaped but much longer effects. In both effects changes of the delta and fast wave powers were well correlated. Relationships between the individual wave contributions and the anaesthetic concentration were also similarly shaped for alpha and theta waves irrespectively of the agent. However the contributions of the beta waves in sevoflurane anaesthesia at low concentrations during concentration increase were distinctly larger whereas the contributions of delta waves were smaller compared to those in isoflurane and desflurane anaesthesia. Moreover the contributions of individual waves corresponding to increasing and decreasing concentrations manifested only small differences in all the instances but the contribution of delta waves for desflurane.

The inter-subject variability of the values of fast wave powers decreased with the concentration increase whereas that of slow waves was larger and less depended on the concentration. Both the time evolution of individual wave powers as well as the relationships between the wave powers and the concentrations reliably reflected the anaesthetic evoked changes in the EEG structure. The most sensitive as well as invariant in respect to the anaesthetic and inter-subject variability measure of the EEG changes was the relative power of the alpha waves whereas the relative powers of the beta and delta waves were much more dependent on the administrated anaesthetic.

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