EVALUATION OF THE TRADITIONAL SIGNS AND STAGES OF ANESTHESIA: AN ELECTROENCEPHALOGRAPHIC AND CLINICAL STUDY

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Early in the history of general anesthesia the need for observing the reactions of a patient was recognized lest an overdose of anesthetic be given (1). Descriptions of the signs and stages of anesthesia followed (2). Subsequently it became evident that many of the signs were in reality responses to stimuli imposed by the anesthetist or elicited by the stimulus of the surgical procedure (3). Inexperienced and experienced anesthetists alike have relied on these signs for the safe conduct of anesthesia. But newer anesthetic agents and techniques have been introduced which tend to modify the traditional guideposts and doubt has been cast on their value (4). Like others in the field, and especially in teaching beginners, we have felt the need to redefine those signs of anesthesia that are most reliable under all circumstances.

Several workers have employed the electroencephalogram to study the effects of anesthetic agents on brain activity in man (5, 6, 7). This technique and the measurement of arterial blood concentration of anesthetics have been the chief quantitative means of assessing the plane of anesthesia for both research and clinical purposes. These methods have shown wide variations in individuals during what was considered to be a definitive clinical plane of anesthesia. Indeed Faulconer has concluded that, "Correlation of these (electroencephalographic) pattern changes with the commonly accepted signs by which depth of anesthesia is estimated clinically has proved to be inconclusive" (5). As originally introduced the electroencephalogram represented only a crude index of cerebral activity. The source of the brain waves is still obscure and the patterns are influenced by many things other than mere anesthetic content of the brain. Nevertheless, both clinical signs and the electroencephalogram are variables related to the brain content of anesthetic. For this reason we have sought to compare the frequency of appearance of some traditional anesthetic signs with patterns of electrical activity as seen on the electroencephalogram. The work reported here is not an evaluation of the electroencephalogram as a means of detecting the plane of anesthesia. We

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TABLE 1

AGE, SEX, AND PHYSICAL STATUS OF PATIENTS STUDIED FOR SIGNS OF ANESTHESIA

Age Group (years)	Men	Women	Physical Status			
			1	2	3	6
0–10	9	4	9	3	1	
11–20	2		1	1		
21–30	3	2	5			
31–40	5	3	4	2	1	1
41–50	1	2	2	1		
51–60	3	1		2	2	
61–70	7	1		3	4	1
Total	30	13	21	12	8	2

The children were studied at the Children's Medical Center and some of the adults at the West Roxbury Veterans Administration Hospital.

have attempted to define clinical signs of anesthesia that are most indicative of the anesthetic state.

CLINICAL MATERIAL AND METHODS

Table 1 shows the distribution of patients studied with respect to age, sex, and physical status. Table 2 indicates the anesthetic agents administered and type of operation performed. Preoperative medica-

TABLE 2

ANESTHETICS GIVEN AND OPERATIONS PERFORMED DURING STUDY OF SIGNS OF ANESTHESIA

Operations Performed	
Upper abdominal	13
Inguinal	12
Lower abdominal	7
Extremity	6
Superficial	4
Intrathoracic	1
Total	43
Anesthetics	
Nitrous oxide and ether	12
Nitrous oxide, vinethene, and ether	7
Nitrous oxide, ether, and relaxant	3
Thiopental, nitrous oxide, and relaxant	8
Thiopental and nitrous oxide	3
Cyclopropane and relaxant	4
Cyclopropane and combinations with other agents	4
Fluoromar	1
Spinal anesthesia with supplementation	1
Total	43

tion consisted of barbiturate derivatives, analgesics, and belladonna derivatives in combinations as the situation warranted. Most of the anesthetics were administered by senior residents in anesthesia. A second physician observed the electroencephalogram and recorded, on previously prepared forms, the clinical signs as observed by the anesthetist. Anesthesia was administered according to the needs of the surgical procedure. Every effort was made to insure adequate pulmonary ventilation with resort to assisted or controlled respiration when necessary.

The clinical signs observed were those chosen because of common usage and for the ease of detection. They are listed in table 3 with a

TABLE 3

CLINICAL SIGNS STUDIED: MODE OF DETERMINATION

Clinical Sign	Mode of Determination
Respiration	
Intercostal or diaphragmatic movement	Observance of costal movement
Resistance to inflation of the chest with positive pressure	Observance of changes in ability to inflate lungs
Muscular relaxation	
Jaw	Resistance to opening mouth
Forearm	Resistance to flexion and extension
Abdomen	Observation
Ocular signs	
Eyelash reflex	Closure of lid when lash is stroked
Pupillary size	Observation
Pupillary light reflex	Illumination of pupil with bright light
Ocular Movement	Observation
Eyelid tone	Elevation of lid and spontaneous closure
Miscellaneous signs	
Cough	Observation
Laryngospasm	Presence of phonation or complete obstruction

description of the manner of observance and interpretation. It can be seen that elicitation of most of these signs required the imposition of a stimulus. In general they are signs of muscular activity.

Electroencephalographic tracings were taken immediately before induction of anesthesia, continuously during induction, and at intervals during maintenance and emergence. Unilateral fronto-central and fronto-occipital bipolar electrodes were employed. Recordings were made with a Grass electroencephalograph, Model III D, and an Edin Anesthograph. The paper speed was 30 mm. per second and sensitivity 7 mm. at 50 microvolts. Interelectrode resistance was less than

20,000 ohms. Electroencephalographic patterns were interpreted according to the classifications of Faulconer (5), Possati (6), and Kiersey (7). We have assumed that electroencephalographic level I corresponds approximately to stage I of anesthesia; electroencephalographic level II to stage II of anesthesia; electroencephalographic level III to planes 1 and 2 of the third stage of anesthesia; and, electroencephalographic levels IV and V to planes 2 and 3 of the third stage of anesthesia. Henceforth in this discussion the term "level" refers to the electroencephalogram.

Results

General Observations.—In the 43 patients studied some of the clinical signs listed in table 3 did not appear frequently enough to permit analysis. Most of these were in the miscellaneous category. In general, deep planes of anesthesia were not required for the surgical procedures performed. This was especially evident in children on whom the operations were mostly extra-abdominal. In adults, on the other hand, the use of muscle relaxants frequently eliminated the need for greater anesthetic depth with inhalation agents.

It soon became apparent that there was a discrepancy between the clinical signs and the electroencephalographic level especially during induction and emergence. In both situations the clinical signs lagged behind the pattern of the electroencephalogram. During induction patients appeared to be more lightly anesthetized than the electroencephalogram suggested. On emergence clinical depth seemed greater. We have called this the "lag" phenomenon. It was obvious that the charting of clinical signs must be related to the phase of anesthesia whether induction, maintenance, or emergence.

Respiration.—There was a distinct difference in respiratory signs between children and adults. In the younger age groups, with diethyl ether the predominant anesthetic agent, preoperative medication consisted of pentobarbitol, morphine, and atropine in most cases. Before induction of anesthesia respiratory depression could not be detected. Few observations were made during levels I and II. With surgical stimulation respirations increased in frequency in level III early in the course of anesthesia. During maintenance, depression of the volume of respiration was noted frequently in level III but neither intercostal or abdominal respirations predominated. Tracheal tug, sobbing respirations, and phonation were noted once each during maintenance in level III.

In adults receiving pentobarbital, an opiate, atropine or scopolamine, and diethyl ether anesthesia, a decrease in intercostal activity and change to an abdominal pattern did not occur until levels IV and V were reached. When muscle relaxants were employed the pattern of respiration was of little value in helping to determine the plane of anesthesia. Absence, either of intercostal or abdominal activity, or both, was seen at all electroencephalographic levels when muscle relaxants were employed. In all cases with manual control of respiration sudden resistance to inflation of the lungs was associated with level I. At other levels the lungs could be inflated easily. This was true regardless of the anesthetic agent in use.

Muscular Relaxation.—Jaw Relaxation: In the very young, jaw relaxation was present in level I during induction. It was present in all children when level III was reached. This was not surprising in view of the relatively lesser muscle tone in children. However, the stimulus to test jaw tonus was either depression of the mandible or insertion of an oral airway. The type of jaw relaxation needed for laryngoscopy may not have been present. There was a distinct tendency for the jaw to tighten on emergence, occasionally in level III and frequently in level I. In level I pain may have been sensed.

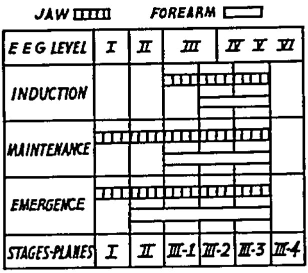

Fig. 1. Diagrammatic representation of the appearance of relaxation of the jaw and forearm, in relation to the electroencephalographic level.

In adults under thiopental and nitrous oxide anesthesia, insertion of an oral airway caused the jaw muscles to tighten in level III. Jaw relaxation was absent during induction and emergence when other agents were employed in adults. Again the muscle relaxants deprived one of the ability to test this sign since relaxation was usually excellent. The general features of this sign may be seen in figure 1. Relaxation usually appeared in level III on induction but persisted through level I on emergence.

Forearm Tonus: This sign was tested mostly in children since the arms were within easy reach and restraints were not commonly used. Counterparts of this sign in the adult were flexion of the fingers when extended, or extension of the legs when placed in stirrups. The general features of forearm tonus followed those of jaw relaxation in time of disappearance and reappearance (fig. 1).

Abdominal Muscle Tonus: It was difficult to assess this sign. In children the type of operation performed did not provide the opportunity to test the abdominal muscles while in adults the muscle relaxants rendered this sign of little value. Adults not given relaxants exhibited varying degrees of tone in level III depending on their age and physical status.

Ocular Signs.—Eyelash Reflex: Almost invariably this sign was lost within a few minutes of the onset of induction while the electroencephalogram still indicated level I. In several instances it could not be elicited at all although the electroencephalogram showed a waking pattern and the patient could respond to verbal commands by voluntarily opening his eyes. It must be clear that the stimulus here was a weak one, that of stroking the lashes, and that the reflex was consequently less important in detecting depth.

Pupillary Size: Figure 2 shows the great variability in the size of the pupil at several electroencephalographic levels. This variability occurred with all agents. A dilated pupil was a common finding in

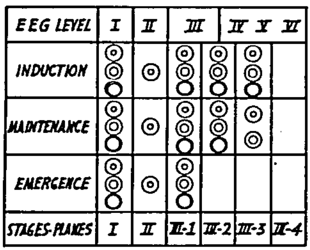

Fig. 2. Diagrammatic representation of the variability in pupillary size in relation to electroencephalographic level. The illustrations show relative rather than absolute pupillary size.

level III with all agents. In a few cases the size remained constant throughout the first three levels and in others the pupil size changed even though the electroencephalographic level did not. Inequality of the pupils was observed in four cases. When pupillary size changed, either with increasing or decreasing depth, this rarely occurred simultaneously with changes in electroencephalographic level but only after a lapse of several minutes. In all patients studied the application of a painful stimulus (skin incision, intra-abdominal manipulation) did not affect the electroencephalographic patterns although the pupils were often seen to dilate. In one case constricted pupils persisted through levels IV and V.

Pupillary Light Reflex: This was not a sign sought in the early stages of anesthesia. Consequently, observations were few during induction. In a few cases the reflex was absent in level I particularly if thiopental had been given. In general this sign persisted through level

III during induction. Once it had disappeared, however, it did not reappear until level I was attained in emergence. In curarized patients this was an ocular sign of value indicating a light level of anesthesia. In children the reflex was frequently absent and never seen in levels II and III. This may have been related to the type of preanesthetic medication given.

Ocular Movement: Both eyes were inspected to detect movement. If movement was not seen an eccentric iris suggested that movement had occurred. If the lids were held apart movement frequently ceased. This sign proved to be a fairly reliable sign of depth during induction of anesthesia. The lag phenomenon was prominent. In children ocular movement was seen up to level III during induction but was never present during maintenance at this level. Movement frequently persisted up to level IV in adults during induction. Again the sign was

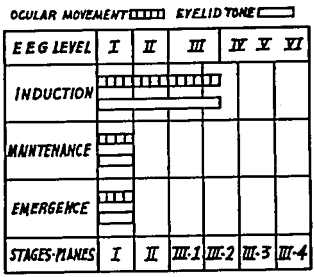

Fig. 3. Diagrammatic representation of the presence of ocular movement and eyelid tone in relation to the electroencephalographic level.

lacking in all during maintenance. It did not reappear on emergence until level I was attained. The general features of ocular movement may be seen in figure 3.

Eyelid Tone: In general eyelid tone followed the pattern of ocular movement. It was a fairly consistent sign and one with a definitive stimulus. Lag, again, was a prominent feature. This sign persisted into level III during induction both in children and adults. During maintenance, though the electroencephalographic level remained stationary at III, the sign was absent and did not return until level I was reached in emergence. The results are summarized in figure 3.

Miscellaneous Signs: Because of the limitations of this study few conclusions could be drawn from the few instances in which signs were observed. Phonation was observed in three cases at levels IV and V. Cough was present at all electroencephalographic levels including one instance in which intubation of the trachea was performed at level V.

Discussion

On first examination the results reported here may seem disparate and confusing. On closer analysis, however, a pattern emerges and certain conclusions can be drawn. It was not to be expected that complete uniformity of anesthetic signs would appear in a group of patients of varying age and physical status and subjected to several anesthetic techniques and different types of surgical operation. It is well known that few individuals exhibit all of the classical signs associated with a supposed plane of anesthesia. Determination of anesthetic depth is not as simple as matching the clinical picture with a theoretical table depicting the signs and stages of anesthesia.

It has been emphasized that determination of the signs of anesthetic depth is frequently a matter of the application of an appropriate stimulus. John Snow implied this in his statement that the surgeon wishes to know if the patient will lie still under the knife (1). Gillespie (3) clarified this concept when he revised Guedel's classification (2) to fit the schema of reflex action. Perhaps the best anesthetic signs are those precipitated by a definitive stimulus from the sensory standpoint. Similarly, the best signs are those for which the end point is definite for the reaction will be clearly perceived. Increased respiration or bodily movement at the time of the surgical incision, tightening of the rectus muscles with stretch, and the presence of lid tone are good examples of definitive responses. Since muscle tone is involved in these it is not surprising that we have found variations in these signs among individuals of different ages and muscular development. In the instances of the eyelash reflex, or of the pupillary reaction to light and the observation of pupillary size, judgment of the response is more difficult. The stimulus is weak and the response likewise. Anesthetic depth is in reality the absence of reflex response. It should be apparent that muscle relaxants eliminate the combination of muscular responses that indicate the plane of anesthesia. Perhaps the only saving grace, is that anesthetic depth need no longer be a consideration. Operations can be performed during a waking pattern on the electroencephalogram. One has more to fear the fact that the patient may be awake and sensing the operation. The ability to respond reflexly is lost. It might be better to discard the concept of anesthetic stages and surgical planes which have relatively little meaning with modern anesthetic techniques and to speak in terms of the minimal reflex depression needed for the performance of an operation.

Results of the examination of respiration as an anesthetic sign re-emphasize well known facts. Age, pre-existing respiratory patterns, preanesthetic medication, anesthetic agents and techniques modify the value of respiration as a sign of anesthetic depth. However, we have noted that increase in respiratory rate, at the application of a surgical stimulus, is a reliable sign of light anesthesia. Resistance to inflation of the lungs seen during light electroencephalographic levels was a helpful sign in the absence of spontaneous respiration. A more extensive study than that reported here probably would have revealed the value of the many accessory respiratory signs other than changes in rate by which anesthetists are guided in the conduct of anesthesia. Some of these are: apnea associated with abdominal manipulation, cough on tracheal stimulation, and tracheal tug with absent intercostal activity.

Jaw relaxation, forearm and abdominal tonus, and lid tone were good anesthetic signs singly, and particularly in combination. Of the ocular signs the eyelash reflex was of little value other than to indicate loss of consciousness initially. Inconsistency of pupillary size might have led us to conclude that this sign is of little value. Few, however, would deny the importance of pupillary dilatation either as a sign of light anesthesia on the one hand or of deep anesthesia and anoxia on the other. As an index of the adequacy of cerebral oxygenation pupillary constriction and dilatation is one of the more reliable signs that we have. The only ocular signs of value in the curarized patient were the reaction of the pupil to light or the reflex dilatation in response to a surgical stimulus. In the presence of these one could be certain as confirmed by the electroencephalogram that the depth of general anesthesia was minimal. If muscle relaxants were not used the presence or absence of lid tone and eyeball movement were additional ocular signs of value when related to induction, maintenance, or emergence.

In the comparison of anesthetic signs with electroencephalographic activity a prominent feature was the "lag" phenomenon. During induction the disappearance of reflexes did not keep pace with changing electrical activity indicative of progressive depth. Similarly during emergence a waking electroencephalographic pattern did not mean that the anesthetic signs would have reverted to the induction pattern. Thus, in eliciting signs of anesthetic depth it is important that the phase of the anesthetic be taken into account, whether induction, maintenance or emergence. This phenomenon has recently been noted by others. Artusio (8) has found it necessary to allow patients to emerge from deeper planes of anesthesia before operations can be performed in the first or analgesic stage. King and Harmel (9) have failed to produce analgesia during induction with ether but have noted analgesia on emergence. The explanation for these observations may lie in part in a difference between arterial and brain content of anesthetic. A period of from ten to fifteen minutes may elapse before equilibrium is reached. This may be purely a physical process. To account for the "lag" phenomenon one might consider the newer theories of anesthetic action. Apparently synaptic transmission in the brain is first affected. This could occur before tissue saturation was in effect and produce early alterations in the electroencephalogram. On emergence from anesthesia, during desaturation of tissues, electrical activity might appear to be normal because of return of certain types of synaptic transmission. Return of more complicated reflex activity might lag behind.

A few remarks about the electroencephalogram seem pertinent. The electroencephalogram was a useful reference in assaying the frequency and time of appearance of anesthetic signs, consequently in evaluating their importance. Our impression is that anesthetic signs in combination are a much more sensitive and practical means of assessing the degree of reflex depression necessary for the performance of an operation. Obviously both methods, the electroencephalogram and anesthetic signs have their limitations. However, far from being discouraged with the traditional signs of anesthesia in this day of new agents and techniques we have emerged with a new respect for their utility and value. How else could competent anesthetists have administered anesthesia safely for over a century?

Summary and Conclusions

The frequency and time of appearance of some of the traditional signs of anesthesia were investigated in relation to the electroencephalogram as a reference point. The clinical material consisted of 43 patients of varying ages submitted to a variety of anesthetic techniques and surgical operations. On first analysis the signs of anesthesia seemed confusing and poorly indicative of the anesthetic state. It became obvious that one could not expect uniformity in a diversified group of individuals. Determination of anesthetic depth according to anesthetic signs was a matter of assaying the degree of reflex reactivity. The best anesthetic signs were those with a definitive reflex response usually elicited by a strong sensory stimulus. Anesthetic signs in their appearance and disappearance tended to lag behind the electroencephalographic level. Some theoretical reasons for this phenomenon were discussed. Respiration, muscle tone and ocular signs singly, and particularly in combination, were valuable indices of the depth of anesthesia. In the presence of paralysis produced by muscle relaxants few signs remained to indicate the extent of reflex depression brought about by the general anesthetic. It would seem to be better practice to avoid reference to the traditional anesthetic stages and surgical planes but to speak in terms of the minimal reflex depression needed for the performance of an operation. The impression was gained that the signs of anesthesia still provide a sensitive and practical means of assaying the depth of anesthesia even with the use of the newer agents and techniques.

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