METHODS

Electrical Stimulation of Labyrinths and Vestibular Reactions

G. I. Gorgiladze

Translated from *Byulleten' Eksperimental'noi Biologii i Meditsiny*, Vol. 138, No. 12, pp. 708-710, December, 2004
Original article submitted August 19, 2003

Stimulation of the labyrinth in rabbits and guinea pigs with ascending (cathode) or descending direct current (anode) induced deviation and nystagmus of the eyes, head turn and tilt, and other reactions. Anodization of both labyrinths was followed by the disappearance of reflexes, suppression of vestibular reactions to adequate stimulation, and loss of swimming ability. The state of animals returned to normal after breaking the electric circuit.

Key Words: *vestibular apparatus; electrical stimulation; labyrinth reflexes; electrode prosthetics*

Electrical stimulation (ES) of the labyrinths attracts much recent attention. This technique holds promise for electrode-implantation prosthetics in patients with severe vestibular dysfunction induced by damage to the receptor apparatus or conduction pathways.

ES can modulate vestibular afferentation in various animal species. The strength of impulses in nerve fibers of the vestibular nerve increased during cathodization, but decreased during anodization of the labyrinth [1,3]. ES abolished changes in impulses from vestibular nuclear neurons induced by caloric stimulation of the labyrinths.

Here we studied the possibility of using electric current for modulation of vestibular reaction in animals.

MATERIALS AND METHODS

Experiments were performed on 18 rabbits (2.5-3.0 kg) and 13 guinea pigs (0.25-0.30 kg). Chlorine-silver electrodes (tip diameter 0.5 mm) were bilaterally implanted into the inner ear under nembutal anesthesia (40-45 mg/kg intraperitoneally). A reference electrode (2×2 cm) was inserted subcutaneously on the neck at the same distance from auditory channels.

Russian State Research Center, Institute of Medical and Biological Problems, Russian Academy of Sciences, Moscow. ***Address for correspondence:*** vaxmail@impb.ru. G. I. Gorgiladze

The labyrinths were stimulated with electric current on a special device [2]. ES of the labyrinths was performed in the following schemes: (1) monaural unipolar stimulation with ascending (active electrode cathode) or descending direct current (active electrode anode) delivered through one of the labyrinths; (2) binaural bipolar stimulation by the cathode and anode applied to various labyrinths; and (3) binaural unipolar (equal) stimulation of both labyrinths with ascending or descending direct current.

Eye movements during ES of the labyrinths were studied by electrooculography. The animals were fixed in a special device. Needle electrodes were implanted into the periosteum at the lateral edge of eye sockets and connected to Teflon-coated stranded cables. The cables passed transcutaneously on the outer surface of the neck.

In some rabbits caloric stimulation of the labyrinths was performed. Auditory channels were rinsed with 5 ml hot (50°C) and cold water (10°C) for 2 min. The animals were subjected to sinusoidal horizontal rotation (90°, 0.25 Hz) and sinusoidal vibration around the longitudinal axis of the body (45°, 0.25 Hz).

RESULTS

Application of the cathode to the right labyrinth (RL) during monaural unipolar ES with 0.12±0.02 mA induced deviation of eyes. The first signs of deviation

0007-4888/04/1386-0629

were observed in response to anodic stimulation with 0.15±0.02 mA. Similar changes were observed during ES of the left labyrinth (LL) with 0.13±0.03 and 0.10±0.03 mA, respectively. Increasing the stimulating current was accompanied by nystagmus of the eyes. We estimated the cathode and anode thresholds for the right (0.40±0.12 and 0.45±0.10 mA, respectively) and left eye (0.35±0.08 and 0.40±0.09 mA, respectively). The direction of deviation and nystagmic beats depended on the polarity of electrodes. Cathodic stimulation was followed by a dorsal deviation of the eyeball at the site of ES. Rapid nystagmic beats were directed backward and ventrally. The contralateral eyeball underwent ventral deviation, and rapid nystagmic beats were directed forward and dorsally. Anodic stimulation of the same labyrinth induced opposite changes. The maximum nystagmic reaction of the eyes to anodization of the labyrinth (3.3-4.0 bpm) was observed at 2.0-2.5 mA and remained practically unchanged after increasing in electric current. A similar reaction was revealed during cathodic stimulation with 2.0-2.5 mA. The reaction became more pronounced (8-10 bpm) with a further increase in electric current. Long-term ES of the labyrinth (1 min) was accompanied by a significant decrease in the nystagmic reaction, but had no effect on deviation of the eyes.

Apart from deviation and nystagmus of the eyes, ES of the labyrinth induced several postural reactions. Anodization of the labyrinth with 0.25-0.30 mA was followed by turning of the head to the site of stimulation (10-15°). Turning (20-30°) and tilt of the head (20-30°) to the site of stimulation were observed after treatment with 0.5-0.6 mA. Increasing the strength of electric current to 1 mA was accompanied by turning and tilt of the head by 30-40 and 45-60°, respectively. We revealed contralateral nystagmus of the head and asymmetric position of the limbs. Turning and tilt of the head increased to 60 and 60-90°, respectively, upon stimulation with 1.5 mA. The animals exhibited manege movements to the site of stimulation, sometimes lost balance and dropped on the lateral side of the body, and rolled over the back. Cathodic stimulation induced similar reactions that were directed to the unstimulated labyrinth. Increasing the strength of electric current in cathodization was accompanied by a greater evoked reaction compared to anodization. The animals completely lost balance and dropped on the lateral side of the body upon stimulation with 0.7-0.8 mA. Rolling over the back to the site of stimulation was observed at 1.0-1.2 mA.

The reaction to binaural bipolar ES of the labyrinths was similar to that observed during monaural stimulation. It should be emphasized that this reaction was induced by ES with a lower strength of electric current.

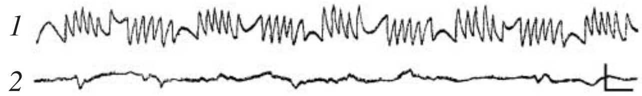

Fig. 1. Nystagmus of rabbit eyes in response to horizontal sinusoidal rotation (*1*); suppression of this reaction by anodization of both labyrinths with 3 mA current (*2*).

Cathodization of both labyrinths during binaural unipolar ES (reference anode) was followed by rotational movements of the eyeballs to the occiput. The eyeballs rotated in a forward direction during anodization of the labyrinths with 0.7-0.8 mA (reference cathode). Nystagmus of the eyes was not observed during cathodization and anodization. Turning of the eyes in a forward or backward direction persisted during the overall period of ES.

Apart from eye movements, cathodization of the labyrinth with 1.2-1.5 mA induced head raising. The reaction increased and was accompanied by extension of the forelimbs upon stimulation with 2 mA. The head tilted down during anodization of the labyrinth with 0.7-0.8 mA. Stimulation with 1.0-1.2 mA induced side-to-side movements of the head and body. Some animals moved back. Wobbling of the body increased, and the limbs moved outwards during treatment with 1.5-2.0 mA. Upon stimulation with 2-3 mA the animals completely lost balance, dropped on the right or left side of the body, and rolled over the back in various directions. The animals lay on the abdomen with extended limbs (with 3.5 mA). They could not retain a normal position of the head, which lay on the floor. The animals lost the ability to swim and drowned in water. These animals resembled bilaterally delabyrinthized specimens. However, the state of experimental animals returned to normal after opening of the electric circuit.

Labyrinth reflexes were preserved during cathodization of both labyrinths with 3 mA. In a head-down position of the animal, its head was slightly elevated. A further increase in the strength of electric current

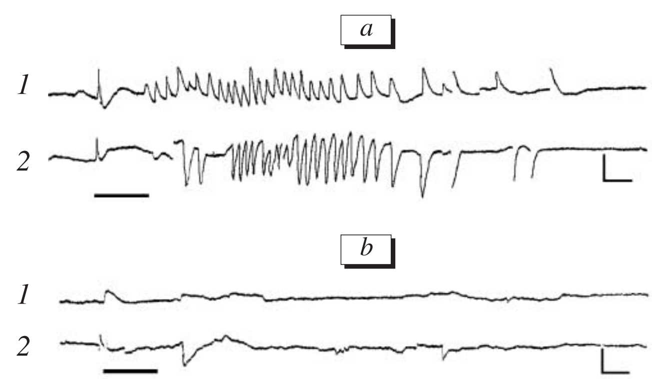

Fig. 2. Nystagmus of rabbit eyes in response to calorization of the right (*1*) and left auditory channel (*2*, *a*); suppression of this reaction by anodization of both labyrinths with 3 mA current (*b*). Horizontal lines: duration of calorization.

was accompanied by the impairment of a reaction to progressive movements. Anodization of the labyrinths with 1.5-3.0 mA attenuated or completely abolished labyrinth reflexes. The head hung down in a head-down position of the animal. The animals did not exhibit readiness for jumping, could not ground on the forelimbs, and beat the head about the floor. They did not turn the body in free fall from a back-down position.

Anodization of RL increased the degree of nystagmus. This treatment stimulated clockwise rotation, but abolished counterclockwise rotations of the eyeball. Cathodization of LL induced similar changes. Anodization of LL and cathodization of RL abolished clockwise rotation, but stimulated counterclockwise rotation of the eyeball.

Caloric nystagmus underwent various changes. Anodization of the labyrinth increased the degree of nystagmus to cold and heat calorization on the ipsilateral and contralateral side, respectively. We observed the reduction of nystagmus to heat and cold calorization on the ipsilateral and contralateral side, respectively. Cathodization of the labyrinth increased nystagmus to heat and cold calorization on the ipsilateral and contralateral side, respectively. This treatment reduced nystagmus to heat and cold calorization on the ipsilateral and contralateral side, respectively.

Anodization of both labyrinths with 2.5-3.0 mA abolished rotational nystagmus and counter-rotation of eyeballs in response to swinging around the longitudinal axis of the body. The treatment reduced nystagmus of the eyes after caloric stimulation of the labyrinths with cold and hot water (Figs. 1 and 2).

Our results suggest that electric current can modify vestibular reactions. Most neurons in vestibular nuclei are regulated by both labyrinths due to the existence of reciprocal and synergistic bilateral interrelations [1]. The Hegies—Bekhterev law of balance centers postulates that ES of the labyrinths improves vestibular reactions when the evoked changes in afferent impulses contribute to the establishment of a vestibular internuclear imbalance, and vice versa. The existence of synergistic bilateral interrelations is manifested when afferent impulses undergo similar changes on both sides of the body. Anodic stimulation of LL and RL abolishes the vestibular reaction and suppresses activity of labyrinths, which is followed by the disappearance of vestibular reflexes and loss of swimming ability.

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