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Research Article

Bionic Eye Prostheses as Means of Communication in Case of the Loss of Both Eyes

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Abstract

Currently, there are no effectively working devices for self-orientation of the blind (including those who have lost their eyes anatomically).

Purpose: To develop a device for helping people with no eyes orient themselves by analyzing the brightness of the light surrounding the user and recording the preserved activity of the oculomotor muscles.

Material and methods: The described device is intended for environmental orientation for blind people who have lost both eye organs anatomically. It consists of the following elements: 1) a video camera with glasses and an information analysis unit (computer with transmissing devices); 2) an eye prosthesis in which microcircuits and a power source are sealed. The user receives the information received by the video camera and the correspondingly processed information by supplying short-term electrical pulses from the electrodes situated on the back surface of the prosthesis.

Results: In laboratory conditions, the devices allowed registration of - as example - the direction of a light source coming from the window in a room or a passing car.

Conclusion: The device will become available for intended usage after carrying out all the prescribed tests and registering in accordance with the established procedures.

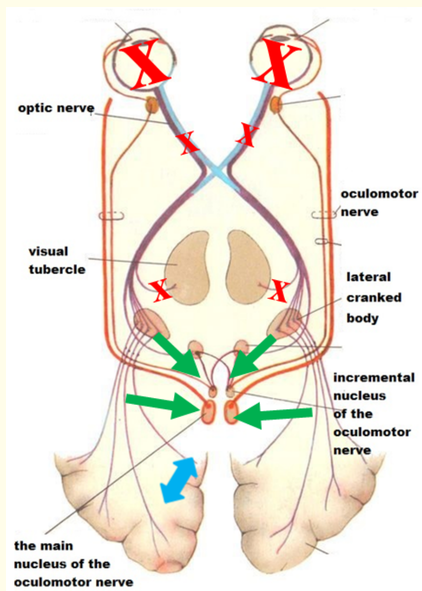
Keywords: *Absence of Eyes, Artificial Eye, Artificial Vision, Bionic Eye Prosthesis, Blindness, Extraocular Muscles*

Introduction

Nowadays the problem of creating devices aimed at helping people who lost vision to navigate in the environment has not been solved at all. And traffic lights equipped with sound signals for the blind as well as service dogs that direct the blind to work prove that idea.

This “wrong” state of affairs is rooted not in the absence of technical means capable of analyzing information indoors and outdoors, but in the absence of an effective way to transmit this information to the user. Actually, the devices to analyze the environment have already been developed and have been used for a long time quite successfully. A control unit in a robotic vacuum cleaner or an autopilot in a car can be used as an example. At the same time all the attempts to employ similar devices for “electronic vision” fail regardless of whether a sound signal or a tactile effect on skin or mucous membrane or even phosphene, caused by pulses from an electrode implanted into cerebral cortex are used.

The problem is that in the transmitting information to the blind an obviously wrong approach is chosen that ignores the preservation of part of the visual analyzer when both eyes are lost. This can be compared to the situation when legs are lost and routine prosthetics is applied to the small remaining stump of a thigh and people without legs are hypothetically taught to crawl with the help of their hands and some devices. Meanwhile, although with eye loss the first neuron of the optic pathway along with optic nerve nuclei die, the nuclei of 3 pairs of oculomotor nerves next to them remain intact. Moreover, they have a link to cerebral cortex and can via corresponding nerves carry out voluntary and involuntary movements of the ocular stump or implant with adjacent ocular prosthesis (Picture 1).



Picture 1

Though the existing literature hasn't provided the author with the reference on what part of visual information the cerebral cortex receives from the nuclei of oculomotor nerves, the significance of the above mentioned facts is unquestionable. Needless to say that a healthy eye when immobilized artificially goes blind, and vision returns only when mobility is resumed [1]. It is also well known that a person can move the ocular prosthesis in different directions voluntary as well as involuntary to respond to some signal. This ability is widely used among laboratories of ocular prosthetics to achieve maximum cosmetic effect.

A device allowing a blind person do without outside help should meet some requirements that are actually have been known for some time already. Thus, the disability classification guide that existed in the USSR since the 50s of the last century said there was a need of outside assistance in case a person had visual field of a healthier eye less than 10 degrees and visual acuity of 0,03 and lower [2]. With all the restrictions these data can be used as reference points while developing devices for the blind. The calculations provided below illustrate how the device that we are currently developing operates. We insist on referring to the device in question as bionic eye prosthesis. As the calculations show, in ideal environment which is a good state of innervation of the orbital cavity mucosa membrane along with the prosthesis mobility we can almost reach the correlation between visual acuity and visual field that were mentioned above and what is more save a person from the need to train a seeing-eye dog.

Methods

The development is intended to provide the blind with the opportunity to use and gradually train the surviving part of the visual analyzer while recording the activity of the oculomotor muscles to stimulate spatial awareness.

The device in question (patent application № a20170162 from 15.05.2017) includes the following elements:

- Spectacle frame camcorder
- Information analysis unit (a computer with transmitting devices)
- The eye prosthesis with microcircuits and power supply source sealed inside (Picture 2).

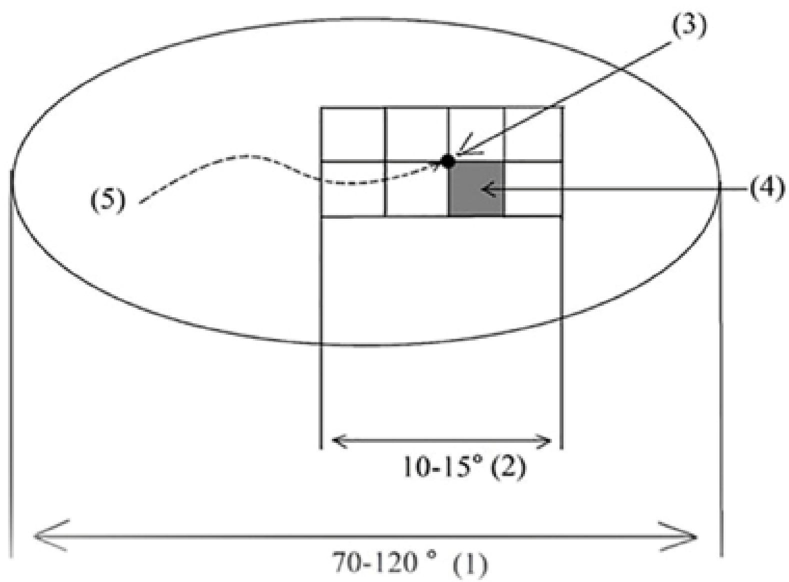
Picture 2

Information transmitting electrodes are output from one of these microcircuits to the posterior surface of the prosthesis and contact the orbital cavity mucosa. A large "grounding" electrode, the one that the patient doesn't feel, is displayed on the front surface of the prosthesis and is in contact with the mucosa of an upper or lower eyelid (Picture 2). We intended to use a gyroscope-axlerometer, a chip, an antenna and a battery in the prosthesis, but this turned out to be impossible without increasing the thickness of the prosthesis and changing its shape. In this regard, in the latest version of the design, only the receiving induction coil for power supply and the chip router are left in the prosthesis itself. In addition, one of the eletrodes is made of iron, magnetized and used as a magnetic tag. The coil has an acceptable thickness of 0.1 mm and is flexible, which allows it to be used in prostheses of different shapes. At the same time, being at a standard vertex distance of 10 mm from the transmitting coil located on the glasses, it allows you to receive voltage... volt and amperage... amperes (wattage... watt). Only the chip increases the thickness of the prosthesis. Currently, chip models are being developed in which most of their elements will be applied to a flexible board, which will make it possible to manufacture bionic prostheses that do not differ from "conventional" ones in geometric parameters.

How the device functions

At the initial stage we don't go far beyond just the analysis of background brightness and of some parts of the environment. The camcorder's field of view is 80 - 120 degrees, but at every taken moment a section of only 10 degrees is active and in constant motion (Picture 3).

And if an object which is significantly different in brightness from the background (darker or lighter than the background) appears, a shirt-term electrical impulse is applied through the electrodes to the certain part of the mucosa under the prosthesis. The patient feels this impulse quite clearly in the form of a slight injection and thus understands what direction this light or shadow comes from. When the user directs the visual axis of the camera towards the object the repeated impulse will be transmitted to the centre of the prosthesis.



Terms that are used to describe the view filed of the device:

1. The general viewing angle of the camera
2. The size of the camera's active viewing part
3. The centre of the active viewing angle
4. The area of the active part which is significantly different in brightness from the rest of the active part. The control unit registers this area as an object and sends an impulse to one of the electrodes at the back of the prosthesis
5. The possible trajectory of the centre of the active viewing angle through the whole viewing angle (corresponds to the rotation of the visual axis)

Picture 3

Results

The sensitivity level of the mucosa of the orbital cavity ranges from 10 to 90 microamps or 0,01 to 0,09 milliamps. The fact that the orbital cavity mucosa and the mucosa of the tip of the tongue have approximately the same level of sensitivity allowed to investigate the optimal modes of the device on ourselves and avoid strict medical compliance.

The optimal electrode size is 1 squire millimeter and the minimal distance between them when perceived separately is 4 - 5 millimeters. Thus from 4 to 8 electrodes can be placed on the back surface of a prosthesis. The minimum time for applying an electrical impulse is 300 milliseconds and time period between impulses (duty cycle) is 400 milliseconds. If we take less time a person stops the perception of separate impulses and perceives them as constant hissing.

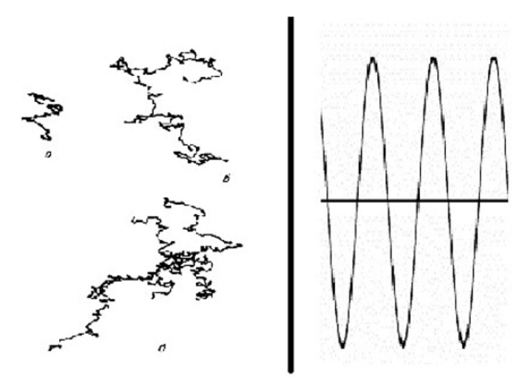
All in all, the whole cycle will take 700 milliseconds.

Changes in the "eye direction" of the bionic prosthesis.

The device is equipped with the software that allows real-time movement of the active part of the camera in any direction which can be compared to the movements of a human eye.

The following types of eye movements are differentiated in literature:

- Jump - voluntary or involuntary eye movement in case we change the target of fixation or follow moving objects - about 30 degrees in 0.01 - 0.02 of a second.
- Reflexive eye movement when a person under test focuses on a motionless target and believes that the eyes are motionless too. This includes three different types of movements the most important of which is drift - smooth eye movements at the speed of about 5 angular minutes per second [picture 4, on the left].



Picture 4.
On the left – the trajectory of the visual axis of a healthy human eye while looking at motionless objects (a drift) according to [1]
On the right – the set trajectory of the centre of the camera's active viewing angle in the device

Picture 4

The camera of our device can also change the direction of its view in two different ways.

- The movement which is similar to a "jump" (described above) of a human eye takes place when the prosthesis changes its position voluntary according to the user's will or involuntarily when there are some stimuli. The mobility of any well-made prosthesis goes up to 30 degrees which almost corresponds to the rotation of a human eye during a jump. The registration of these movements and their display through the corresponding impulses on the electrodes enables the user to determine the direction and in some cases define the size of the adjacent objects.

- The device's software makes it possible to create a relatively slow change in the direction of the camera's gaze similar to the drift (described above) when the camera is motionless (no jumps) [picture 4, on the right]. This type of movement is generated automatically and occurs regardless of the presence of external stimuli or the user's will. The resolution of the device can be doubled at this type of movement.

In laboratory models we managed to register the direction of a light source for the blind, for instance bright window or a dark door inside or a car passing by outside.

Discussion

The assessment of possible effectiveness of the device.

If the viewing angle of the camera (field of view) is 10 degrees and 8 active electrodes are used on each prosthesis (16 all in all) we obtain a matrix of 4 by 4 electrodes. Accordingly, the angular distance between the electrodes will be 2.5 degrees or 150 angular minutes which corresponds to the visual acuity of 0.066. "The drift" of the camera's view will help to increase the resolution of the device up to 0.01 - 0.015.

An important feature of the bionic ocular prosthesis lies in its compatibility with any devices that transmit information through other analyzers (for example ultrasonic locators).

Conclusion

The possibility of using the described devices for the rehabilitation of people who have lost both eyes changes the requirements for enucleation surgery. Maintaining the best possible innervation of the mucosa will allow to increase the number of electrodes working on the prosthesis and consequently to improve the device's resolution. On the one hand, the most careful enucleation is required to reduce scarring. On the other hand, in some cases microsurgical operations may be needed to restore innervation and blood supply of the orbital cavity mucosa. It is also necessary to study the influence of the implant's size and material on the mucosa's condition.

- For a number of reasons, a gyroscope and an accelerometer of the device, the largest energy consumers, are located in the prosthesis itself. A large amount of electronics makes the prosthesis heavier, what is more, the concern to make the device as thin as possible prevents us from placing the antenna in it for contactless power supply, what leads to the using of batteries. At the same time, we could not place the above mentioned electronic equipment in the implant which has much more space enough to locate the antenna and provide contactless power from external sources (placed on the frame).

- Under these circumstances the usage of the microcircuit seems to be a sound idea, as it will help to determine the movement of the implant in case of removing the only eye (sore or blind) or when there is a threat of losing a paired eye in the result of a serious disease.

- Regardless of how the device receives information (visible light, ultrasound, laser radiation) and how the information is transmitted to the patient (electrical impulse to the mucous membrane or phosphene to the cerebral cortex) we still will have to use the remainder of the visual analyzer through the registration of eye prosthesis movements. Moreover, ophthalmologists will be needed to assist in rehabilitation process of people with bilateral loss of eyes.

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