Receptors of the sight sense and genesis of the eye lens transparency

Farbiszewski R., Kranc R.*

School of Medical Science in Bialystok, Poland

ABSTRACT

Visual perception begins with light absorption through photoreceptors called plugs and rods onto the retina. Under the influence of light, stimulated photoreceptors of the retina induce physic-chemical changes of pigment substances, arising due to biological signals. Then, they are transmitted through the lateral geniculation body of processing system and finally centre of vision cortex, called front temporal areas, where follows definitely conscious image of vision. When the fetus' young lens cells contain all organelles and nuclei, it is not transparent, because they represent potential sources of light scattering. Later, in the fiber cell, differentiation process of all the intracellular organelles, including the nucleus are degraded through apoptic mechanisms. Organelle breakdown eliminates light scattering structures from optical axis and ensures the transparency of the tissue. This review article presents new, useful information about the eye lens, epithelial cells and fiber cells.
Key words: photoreceptors, medial temporal lobe, lens in foetus, organelle breakdown in lens

***Corresponding author:**
School of Medical Science
Krakowska Street 9
PO BOX 15-875 Białystok (Poland)
Tel: +48857499434, Fax: +48857499431
E-mail: robertkranc@op.pl (Robert Kranc)

Received: 11.04.2012
Accepted: 28.06.2012
Progress in Health Sciences
Vol. 2(1) 2012 pp 142-146.

1. Receptors of the sight sense

Visual perception begins with light absorption through photoreceptors called plugs and rods onto the retina. Both types of receptors make up the inside layer of the wall of the eyeball. They are considered natural optical fibers because of their highly specialized shape and optical properties [1]. Where, cells fulfill a wide range of physiological functions to support the activity and survival of retinal neurons [2]. They play a key position in the path of light through the retina, where photoreceptor cells, plugs and rods, receive incidental light. Plugs allow color recognition and ensure the receipt of highly differentiated light stimuli and precise vision, whereas rods play a key role in black/white sight in the semi-darkness. In patients with pigmental degeneration of the retina or macular degeneration, these cells decay. The plug and rod membrane accumulates abundant amounts of cyclic guanosine monophosphate (cGMP), synthesized by the enzyme guanyl cyclase. cGMP acts as secondary transmitter, modifying the protein structure in the sodium channel of the wall of rods and plugs. The signal is then transmitted through many structures of the processing system, according to the law of optotopic organization, through the lateral geniculation body and the visual cortex. At present, most authors assume that normal perception depends on neural processing in an optical visual pathway. However, the further the sight information travels, the more specialized the processing. The information reaches largely non-sensory cortex centers [3] that are likely essentially important in the perception and recognition of objects [4]. Visual information processing occurs in these cortex centers. Neurons in visual cortical areas are comprehensively integrated, forming neural correlates of perceptual vision in the human brain [5, 6] but the exact processing procedure for a single visual image is not known. Most studies in humans of conscious visual perception, using psychophysiological techniques as well as functional magnetic resonance imaging (fMRI), have shown that only some areas of the brain maintain neural activity. These neuroimaging techniques are used to study the structures and function of the neural system, and are also used as diagnostic tools to detect altered states of consciousness [7]. Measuring changes in blood flow in particular areas makes it easy to record neuron activity in the temporal lobe. Moreover, the technique of neuroimaging delivers maps of brain activity after regions are stimulated [8]. Lumer and Rees [6] from the University of London have shown that the temporal lobe in humans is stimulated during conscious stimulus action. It should be emphasized that numerous cortical neurons may correspond to stimuli of which we are not conscious. Changes in neural activity in the medial temporal lobe (MTL) induced by conscious vision perception are more easily observed using functional brain imagining, in comparison with the action of inexplicit stimuli [3]. The same changes in the neuronal network of the temporal lobe were observed in studies in monkeys [4].

However, current discoveries point out very clearly that conscious perception cannot be considered the final stage of signal processing. Perception should be understood as engaging all visual pathways and central areas of the frontal and parietal lobes, which participate in higher cognitive processing [5]. These cortical structures are also responsible for analysis and conscious decisions about visual stimuli.

Evidence from several recent lines of empirical neuroscience suggests that the frontal and parietal cortexes and their continuous interaction with the layer-level sensory brain region play a causal role in generating perceptual states [3]. These interactions are more directly concerned with the processing of sensory stimulus properties [9].
These two above-mentioned regions have been implicated in selective visual spatial attention. Electrophysiological observations in monkeys indicate that the parietal and pre-frontal structures of the cortex are reciprocally connected and act in concert with these findings in visual areas [10-12].

According to Blackmore and Frith [13] and Jackson and Decety [14], the temporoparietal junction is thought to be involved in the integration of sensory information related to the external world and external space.

It should be emphasized that brain processes create conscious states not only under the influence of sensoric stimuli, but also from memory signals resulting from earlier experiences. It is the scientist's task to recognize the joint neural network that serves to selectively integrate visual events and contribute to conscious perception. Despite the relatively large number of studies examining neural visual pathways, the neural mechanism leading to the awareness of visual stimulus remains unclear. Further uninterrupted development along these lines is predicted by many experts.

2. Genesis of the eye lens transparency

In the last ten years, scientists have made an important discovery on the lens of the human eye. It is the only transparent tissue in the human body and, according to many authors, it is a 'biological crystal' (optical homogeneous). The role of the lens in the optical train of the eye is to focus light sharply on the retina. Various ageing disorders, UV light and/or damage to the lens will lead to its clouding and ultimately to a cataract. When the lens of the human eye comes into being

during the early embryonic stage, the cells that are designated to become the lens activate an unusual program in their development. When the fetus' young lens cells contain all organelles and nuclei, it is not transparent, because they represent potential sources of light scattering. However, as it continues to develop, it degrades its cellular structures and nuclei [15]. Organelle degradation is triggered in the center of the lens during embryonic development and is characterized by the rapid and coordinated disappearance of all membrane-bound organelles [16]. This process occurs over a period of a few hours only within the region of the lenses and results in the formation of a central, organelle-free zone [17]. The dissolution of fiber nuclei is preceded by changes in shape of nuclear lamina until they break down [18]. Ultimately, DNA nucleoside-sized fragments are released. Only one organelle remains, which is an uninjured, dense protein fluid called crystalline [19]. The programmed elimination of cytoplasmic organelles occurs during the terminal differentiation of lens fiber cells. A program is able to stop this process before it results in the total destruction of the cells and thus keeps the remaining cell membrane and crystalline uninjured. The cellular nucleus loss has an important consequence, which is the loss of any genetic programming that could regenerate or simply repair the lens in case of damage. The loss of repair possibilities, especially the lens' sensitivity to some factors, causes changes in its coefficient of light refraction.

The ability to exchange damaged structures for functional ones is a basic virtue of any biological system. Biomolecules that build human cells should form within a few minutes to a few days.

However, lens cells should be functional for the entire duration of the human's life. The failure of the degradation program is a striking feature of many types of cataracts in animal models. This process is also inhibited in strains of mice with hereditary cataracts, in mice that lack specific genes [20, 21], in mice with a genetic mutation and in cases of tryptophan deficiency [22].

Nashimoto et al.'s [23] studies confirm that a lack of decomposition of nuclei and their degradation causes nuclear cataracts in the mouse lens due to the accumulation of undigested DNA in the cytoplasm of fiber cells. Scientists have sought to identify the enzymes responsible for the lens structure degradation, and they detected several nuclease activities [24].

DNases may be grouped into three functional categories: Mg^{2+} – dependent endonucleases, Ca^{2+}/Mg^{2+} – dependent endo-nucleases (e.g. DNase I) and acidic cation independent nucleases (e.g. DNase II and DNase IIβ). To date, the molecular mass of DNase II has been determined [25]. DNase IIβ is necessary for fiber denucleation [26]. The enzyme is restricted to the lens in lysosomes, and it fuses the nucleus of the fiber cell, protecting against the degradation of chromatin [24]. These results suggest that the lysosomal system plays a key role in the degradation of cellular organelles. Endogenous phosphatases and dephosphorylating DNA under an acidic condition have been also identified in lenses [27, 28]. Organelle degradation is triggered in the center of the lens during embryonic development and is characterized by the rapid and coordinated disappearance of all membrane-bound organelles, including nuclei, endoplasmic reticula and Gold apparatuses [16]. This process removes potential scattering elements from the light path, and it is believed that cytokine proteases called caspases (caspase-3 and caspase-6) are involved in the apoptic machinery [29]. Both types of caspases occur in inactive form. After receiving an apoptic signal, the caspases cleave from their inactive precursors and thus take their active, mature form.

Furthermore, a family of calcium-dependent cysteine proteases – calpains – occur in abundance in the lens and play a crucial role in organelle degradation and programmed cell death [29-31].

Their cleavage probably concerns numerous cellular proteins in all stages of cellular existence, from proliferation and differentiation to death. There is also growing evidence of calpain involvement in apoptosis execution in certain pathological conditions. However, researchers do not yet possess a full understanding of the mechanism of its function in apoptosis.

Some recent studies have proposed that calpains cleave proteins and thus modify the function of target proteins (i.e., protein p53) by removing a peptide that blocked the substrate activity [30, 32, 33]. It is worth stressing that the calpain's important role in apoptosis is the disruption of mitochondrial membrane potential, which leads to the release of cytochrome c and the formation of apoptic-protease activating factor. Finally, this finding implies that organelle breakdown may occur through multiple independent pathways, so researchers' under-standing of the mechanism of this pathway in apoptosis is not comprehensive yet.

CONCLUSIONS

The photoreceptors called plugs and rods within the retina are responsible for sight perception. They respond to biological signals by causing physic-chemical changes in the pigment substances, which are transmitted to the center of the vision cortex, called the medial temporal lobe. This review article presents new, useful information about the eye lens, epithelial cells and fiber cells.

Conflicts of interest
We declare that we have no conflicts of interest.

REFERENCES

1. Franze K, Grosche J, Skatchkov SN, Schinkinger S, Foja C, Schild D, Uckermann O, Travis K, Reichenbach A, Guck J. Muller cells are living optical fibers in the vertebrate retina. Proc Natl Acad Sci U S A. 2007 May 15; 104(20): 8287-92.
2. Bringmann A, Pannicke T, Grosche J, Francke M, Wiedemann P, Skatchkov SN, Osborne NN, Reichenbach A. Müller cells in the healthy and diseased retina. Prog Retin Eye Res. 2006 Jul; 25(4): 397-424.
3. Leopold D.A, Logothesis NK. Multistable phenomenon changing views in perception. Trends Cogn. Sci. 1999 Jul; 3(7): 254-64.
4. Logothetis NK, Pauls J, Augath M, Trinath T, Oeltermann A. Neurophysiological investigation of the basis of the fMRI signal. Nature. 2001 Jul 12; 412(6843): 150-7.
5. Lumer ED, Friston KJ, Rees G. Neural correlates of perceptual rivalry in the human brain. Science. 1998 Jun 19; 280(5371):1930-4.
6. Lumer ED, Ress G. Covariation of activity in visual and prefrontal cortex associated with subjective visual perception. Proc Natl Acad Sci USA. 1999 Feb 16; 96(4): 1669-73.
7. Thonnard M, Boly M, Bruno MA, Chatelle C, Gosseries O, Laureys S, Vanhaudenhuyse A.
1. Neuroimaging technique: a diagnostic tool to detect altered states of consciousness. Med Sci. 2011 Jan; 27(1):77-81.
8. Logothetis NK, Schall JD. Binocular motion rivalry in macaque monkeys: eye dominance and tracking eye movements. Vision Res. 1990; 30(10): 1409-19.
9. Sterzer P, Kleinschmidt A, Rees G, The neural basis of multistable perception. Trends Cogn Sci. 2009 Jul; 13(7): 310-8.
10. Wilson FA, Scalaidhe SP, Goldman-Rakic PS. Dissociation of object and spatial processing domains in primate prefrontal cortex. Science. 1993 Jun 25; 260(5116): 1955-8.
11. Miller EK, Desimone R. Parallel neuronal mechanisms for short-term memory. Science. 1994 Jan 28; 263(5146): 520-2.
12. Chafee MV, Goldman-Rakic PS. Matching patterns of activity in primate prefrontal area 8a and parietal area 7ip neurons during a spatial working memory task. J Neurophysiol. 1998 Jun; 79(6): 2919-40.
13. Blackmore SJ, Frith C. Self-awareness and action. Curr Opin Neurobiol. 2003 Apr; 13(2): 219-24.
14. Jackson PL, Decety J. Motor cognition: a new paradigm to study self-other interactions. Curr Opin Neurobiol. 2004 Apr; 14(2): 259-63.
15. Dahm R, Prescott AR. Morphological changes and nuclear pore clustering during nuclear degradation in differentiating bovine lens fibre cells. Ophthalmic Res. 2002 Sep-Oct; 34(5): 288-94.
16. Bassnett S. Lens organelle degradation. Exp Eye Res. 2002 Jan; 74(1):1-6.
17. De Maria A, Bassnett S. DNase IIbeta distribution and activity in the mouse lens. Invest Ophthalmol Vis Sci. 2007 Dec; 48(12): 5638-46.
18. Bassnett S. On the mechanism of organelle degradation in the vertebrate lens. Exp Eye Res. 2009 Feb; 88(2):133-9.
19. Horwitz J. Alpha-crystallin. Exp Eye Res. 2003 Feb; 76(2):145-53.
20. Graw J, Löster J, Soewarto D, Fuchs H, Meyer B, Reis A, Wolf E, Balling R, Hrabé de Angelis M. Characterization of a mutation in the lens-specific MP70 encoding gene of the mouse leading to a dominant cataract. Exp Eye Res. 2001 Dec; 73(6): 867-76.
21. Min JN, Zhang Y, Moskophidis D, Mivechi NF. Unique contribution of heat shock transcription factor 4 in ocular lens development and fiber cell differentiation. Genesis. 2004 Dec; 40(4):205-17.
22. Vrensen GF, van Marle J, Jonges R, Voorhout W, Breipohl W, Wegener AR. Tryptophan deficiency arrests chromatin breakdown in secondary lens fibers of rats. Exp Eye Res. 2004 Mar; 78(3): 661-72.
23. Nishimoto S, Kawane K, Watanabe-Fukunaga R, Fukuyama H, Ohsawa Y, Uchiyama Y, Hashida N, Ohguro N, Tano Y, Morimoto T, Fukuda Y, Nagata S. Nuclear cataract caused by a lack of DNA degradation in the mouse eye lens. Nature. 2003 Aug 28;424(6952):1071-4.
24. Nakahara M, Nagasaka A, Koike M, Uchida K, Kawane K, Uchiyama Y, Nagata S. Degradation of nuclear DNA by DNase II-like acid DNase in cortical fiber cells of mouse eye lens. FEBS J. 2007 Jun; 274(12): 3055-64.
25. Evans CJ, Aguilera RJ. DNase II: genes, enzymes and function. Gene. 2003 Dec 11; 322: 1-15.
26. De Maria A, Bassnett S. DNase IIbeta distribution and activity in the mouse lens. Invest Ophthalmol Vis Sci. 2007 Dec; 48(12): 5638-46.
27. Umeda IO, Nakata H, Nishigori H. Identification of protein phosphatase 2C and confirmation of other protein phosphatases in the ocular lenses. Exp Eye Res. 2004 Dec; 79(6): 385-92.

28. Nakagami Y, Ito M, Hara T, Inoue T, Matsubara S. Nuclear translocation of DNase II and acid phosphatase during radiation-induced apoptosis in HL60 cells. Acta Oncol. 2003; 42(3): 227-36.
29. Zandy AJ, Bassnett S. Proteolytic mechanisms underlying mitochondrial degradation in the ocular lens. Invest Ophthalmol Vis Sci. 2007 Jan; 48(1): 293-302.
30. Goll DE, Thompson VF, Li H, Wei W, Cong J. The calpain system. Physiol Rev. 2003 Jul; 83(3):731-801.
31. Zandy AJ, Lakhani S, Zheng T, Flavell RA, Bassnett S. Role of the executioner caspases during lens development. J Biol Chem. 2005 Aug 26; 280(34): 30263-72.
32. Łopatniuk P, Witkowski JM. Conventional calpains and programmed cell death. Acta Biochim Pol. 2011; May 58(3): 287-96.
33. Perin BJ. Huttenlocher A. Calpain. Int J Biochem Cell Biol. 2002 Jul; 34(7):722-5.