Basics of the action of monochromatic visible and near IR (laser) radiation on cells

T.Karu
LaserTechnology Research Center of Russian Acad. Sci., 142092 Troitsk, Moscow Region, Russian Federation

QUANTITATIVE LAWS OF LIGHT ACTION

1. Irradiation with visible or near IR radiation at certain doses, intensities and wavelengths may stimulate the proliferation of mammalian cells, as well as the growth of prokaryotic and eukaryotic microorganisms.
2. The main regularities in irradiating cells with continuous wave (CW) light are as follows:
   (a) There is a bell-shaped fluence vs. biological effect curve characterized by a threshold, a distinct maximum, and a decline phase. However, there are exceptions from this rule.
   (b) In most cases, the final photobiological effect only depends on the radiation dose and not on the radiation intensity and exposure time (the reciprocity rule holds true), but sometimes the reciprocity rule proves invalid.
   (c) Though the biological responses of various cells may be qualitatively similar (e.g. characterized by bell-shaped dose dependences), they may have essential quantitative differences as was establised for various yeast organisms.
   (d) The biological effects of irradiation do depend on wavelength (action spectra). The action spectra for both eukaryotic and prokaryotic cells are of the same type, having maxima in every visible light band.
3. The biological responses of the same cells to pulsed and CW light of the same wavelength, average intensity, and dose, can be different.
4. The main regularities when irradiating cells with pulsed light are as follows:
   (a) Dose dependences have more than one maximum. The reciprocity rule holds in all maxima of these curves.
   (b) There is strong dependence on the pulse repetition rate, pulse duration, and quite probably, on the duty cycle.

PRIMARY MECHANISMS OF LIGHT ACTION

1. The terminal respiratory chain oxidases in eukaryotic cells (cytochrome c oxidase) and in the prokaryotic cells of the bacterium *Escherichia coli* (cyt bd and cyt bo complexes) are believed to be photoacceptor molecules for red-to-near-IR radiation. In the violet-to-blue spectral region, flavoproteins (e.g. NADH-dehydrogenase) are also among the photoacceptors as well as terminal oxidases.
2. It is suggested that the photoacceptor is not the fully reduced or oxidized enzyme, but one of its intermediate forms (a so-called mixed valence oxidase), which has not yet been identified.
3. At least four types of reactions can occur with the participation of a photoacceptor molecule after its electronic excitation: changes in redox properties and the acceleration of electron transfer, one-electron auto-oxidation ($O_2^{\bullet-}$ formation), photodynamic action ($^1O_2$ formation), and changes in biochemical activity induced by the local transient heating of the absorbing chromophores. It is unreasonable to believe that only one of these reactions occurs under irradiation. The question is which one is responsible for the specific cellular responses under study? Recent experimental results indicate that changes in redox properties of absorbing chromophores in photoacceptor molecule might have a great importance.

SECONDARY REACTIONS

The primary physical and/or chemical changes induced by light in the photoacceptor molecules are followed by a cascade of biochemical reactions in the cell which require no further light activation and occur in the dark (photosignal transduction and amplification chains). These reactions are associated with the changes in the cellular homeostasis parameters. The crucial step here is thought to be the alteration of the cellular redox state.

CONTROVERSIES AND LIMITATIONS

1. The diversity of low-power laser effects on the cellular level can be explained by the similarity in principles of respiratory chain function.
2. Variations in the magnitude of low-power laser effects on the cellular level are explained by the overall redox state of the cells at the moment of irradiation. The cells with a lowered internal pH, pH_i (whose redox state is shifted to the reduced side) respond more strongly than the cells with the normal pH_i value.
3. It is suggested that such pathological conditions as chronic inflammation and indolent wounds respond to irradiation because of their lowered pH value and hypoxia. Irradiation can also affect the stimulus-

response-recovery cycle which naturally includes changes in step of redox state and pH_i.

4. Irradiation with low and high doses of light of the same wavelength causes different reaction channels to prevail, which results in different cellular responses: stimulation of the vital activity or its inhibition or even destruction.
5. There are biological limits in low-power laser effects: the proliferation of fast-growing cells can not be stimulated, or not all cellular functions can be activated. Also, not all species among yeast strains, *E. coli* mutants, and cells cultivated *in vitro* can be stimulated by irradiation.
6. Not all cells in tissues or cellular cultures will respond to irradiation in exactly the same way. The reason is the heterogeneous nature of the cell cultures and tissues (with regard to their proliferative activity, for example).
7. When complex systems like blood or spleen cell suspensions are irradiated, the irradiation effect (its magnitude or even the nature of the response, stimulation or inhibition of some parameter) depends on the physiological status of the host organism.

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