Ablation, Dissection, and Transport of Biomaterials using Fs and Ns Laser Pulses

Alfred Vogel

Institute of Biomedical Optics, University of Luebeck, Peter-Monnik Weg 4, 23562 Luebeck, Germany

The mechanisms of short-pulsed laser ablation, dissection, and transport will be analyzed based on the results of time-resolved photography and numerical simulations.

Tissue ablation usually relies on linear absorption of tissue water and biomolecules while fs laser ablation always involves nonlinear absorption and plasma formation. Ablation consists of primary material ejection driven by explosive phase transitions and secondary ejection caused by the recoil stress from primary ejection.

Ns ablation progresses as a cascade of different phase transitions of the tissue water including non-equilibrium surface vaporization, phase explosion, and explosive vaporization from a supercritical state. These phase changes and the subsequent recoil-induced material expulsion are modified by rupture and photothermal dissociation of the tissue matrix.

When ultrashort pulses are used, the energy deposition is stress-confined. Tensile thermoelastic stresses facilitate explosive phase transitions in the tissue water and can also directly contribute to ablation via fracture of the tissue matrix.

Dissection inside of transparent biomaterials relies on nonlinear energy deposition via plasma formation. It is used for intraocular microsurgery, refractive surgery, and nanosurgery of cells.

Fs laser nanosurgery is characterized by the formation of low-density plasma followed by chemical effects of the free electrons (bond breaking), thermal effects, and compressive and tensile thermo-elastic stress waves that produce transient cavitation bubbles. Dissection using oscillator pulse trains at >> 1 MHz is usually performed at energies well below the bubble formation threshold and thus mediated by accumulative free-electron-induced chemical decomposition, possibly in conjunction with multiphoton-induced chemistry. By contrast, dissection with < 1 MHz repetition rate uses ≈10-fold larger pulse energies and relies on thermoelastic formation of minute transient cavitation bubbles ranging in size from ≈ 100 nm up to a few micrometers.

We recently discovered that nano-bubbles can be created also by UV and VIS nanosecond pulses with a smooth pulse shape (including those from a microchip laser). For energies 10-30 times above the bubble threshold, the plasma then suddenly assumes a larger size, luminesces brightly, and much larger bubbles of 200 μm radius are produced. The two-step process was successfully modeled considering thermal ionization besides multiphoton and avalanche processes.

Laser-induced separation of histologic specimens and live cells by means of UV-A ns pulses (337 nm) is a well established technique consisting of two steps: Isolation of the probe by laser micro-dissection (LMD) is followed by laser 'catapulting' (LC) of the probe into a target container. LMD relies on plasma formation, and LC on plasma formation or explosive ablation, depending on laser spot size. Pressures up to 700 MPa accelerate histologic specimens to up to 300 m/s, and cells to 50-60 m/s. Side effects were assessed by thermal calculations, real-time RT-PCR, and recultivation studies. Catapulting with tightly focused or strongly defocused pulses results in little collateral damage, while slight defocusing involves significant heat and UV exposure. Optimum strategies for transporting live cells adherent to a polymer membrane could be identified. New avenues for the improvement of the separation and transport processes will be discussed