Ultrafast Protein Dynamics with Biological Mutation

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Protein dynamics is a complex process and the current challenge is to break down its complexity into elementary processes which act on different time scales and length scales. We integrate *femtosecond spectroscopy, molecular biology techniques,* and *computational simulations* to follow the system evolution in real time and thus elucidate the complex dynamics with unprecedented detail. Here, we report two important biological systems of protein surface hydration and light-driven DNA repair by photoenzyme (photolyase). With femtosecond temporal and single-residue spatial resolution, we mapped out the global water motion in the hydration layer using tryptophan residue to scan the protein surface with site-directed mutagenesis. The obtained results reveal the ultrafast nature of surface hydration dynamics and provide a molecular basis for protein conformational flexibility, an essential determinant of protein function. By altering chemically and structurally important residues of photolyase with mutation, we identified key residues in catalytic reactions and followed the entire functional evolution of DNA repair. We resolved a series of ultrafast processes including active-site solvation, energy harvesting and transfer, and electron hopping and/or tunneling. These results elucidate the crucial role of ultrafast dynamics in biological function efficiency and lay bare the molecular mechanism of DNA repair at atomic scale.