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Quantitative assessment of thermal dose using photographic measurements of tissue discoloration

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High Intensity Focused Ultrasound (HIFU) is rapidly gaining widespread clinical use in China, and is undergoing regulatory evaluation in Europe and the US for many target diseases. Nevertheless, tools for therapy planning, monitoring, and assessment remain at a rudimentary level. In particular, measurement of thermal dose in tissues exposed with HIFU has not been sufficiently quantitative to make detailed comparisons with numerical simulations, required for validation of therapy planning models. Indeed, model validation is complicated by high sensitivity of the results to small changes in parameter values and by the general difficulty of performing geometrical registration with sufficient precision to meaningfully compare millimeter scale features typical of HIFU lesions. Our work uses photographic measurement of visible tissue discoloration so that it can be used to accurately and rapidly quantify HIFU-induced bioeffects at scales of several centimeters for comparison with the prior therapy plan. Precise comparison between nonlinear acoustic simulation and macroscopic lesion data indicates that a newly defined "blanching index" is nearly linearly proportional to the logarithm of predicted thermal dose over a very wide range of exposure, including well below the 240 minute (at 43 degrees) necrotic threshold up to about 10,000 minutes.