Damage Theory

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Classical Theory

Classical theory (widely accepted, Saparto and Dewey, 1984) is based on the assumption that damage is measured by

$$TD(t) = \int_0^t r^{(43-T(t))}\,dt \qquad r = \begin{cases} 0.25 & T \leq 43^o C \\ 0.50 & T > 43^o C \end{cases}$$

This formula

- is entirely phenomenological/heuristic (has no mechanistic basis);
- Damage threshold varies widely among different tissues;
- No explanation of the significance/origin of the threshold at 43^oC.

Another Idea

In paper by Zhou, Chen, and Zhang, 2007, it was suggested that damage is the result of irreversible, protein denaturization, governed by the chemical reaction

$$P \rightarrow D,$$

(P = folded protein, D = denatured protein) at an Arrhenius reaction rate

$$r(T) = A \exp(-\frac{\Delta G}{RT})$$

where ΔG is activation energy, R is universal gas constant. This leads to damage fraction

$$\Omega(t) = \log(\frac{P_0}{P(t)}) = \int_0^t A \exp(-\frac{\Delta G}{RT(t)})dt$$

(P_0 = initial folded protein).

Comments

- While this formula was used for damage from a laser, we believe it is also applicable to damage from ultrasound (HIFU);
- The parameters A, ΔG and Ω_θ (damage threshold) can be chosen to match different tissue types.
- $\Omega(t)$ can be readily computed using the Pennes model (described above).