Electromagnetic macro-dosimetry of murine skin at millimetre wave

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Outline

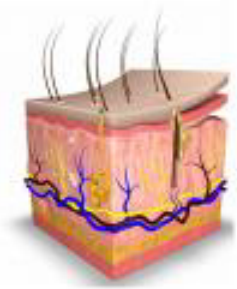
- Introduction
- Skin anatomy description
- Identification of time variable parameters impacting dosimetry
  - Skin layer dimensions during a hair cycle
  - Dielectric properties (permittivity, conductivity)
- Model description
- Results
- Conclusions

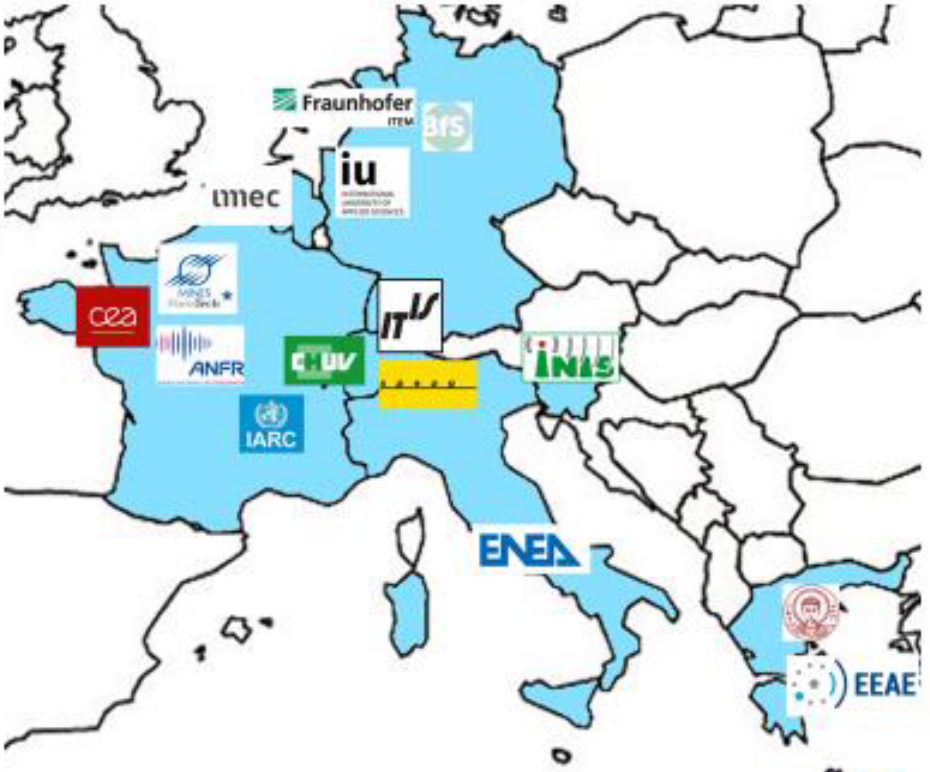
Introduction

Scientific-based **E**xposure and risk **A**ssessment of radiofrequency and mm-**Wave** systems from children to elderly (5G and Beyond)

Aims at filling the knowledge gaps in:

- Exposures from Cellular 5G vs. 2G–4G Networks
- Exposures from New 5G Local Networks in Workplaces
- Exposure Monitoring from 5G MaMIMO Base Stations
- Exposure Assessment of End User Devices
- Macro and Microdosimetry in the Human Skin
- Skin Cancer & Other Skin Diseases from 5G FR2
- Citizen's Perceived Exposure





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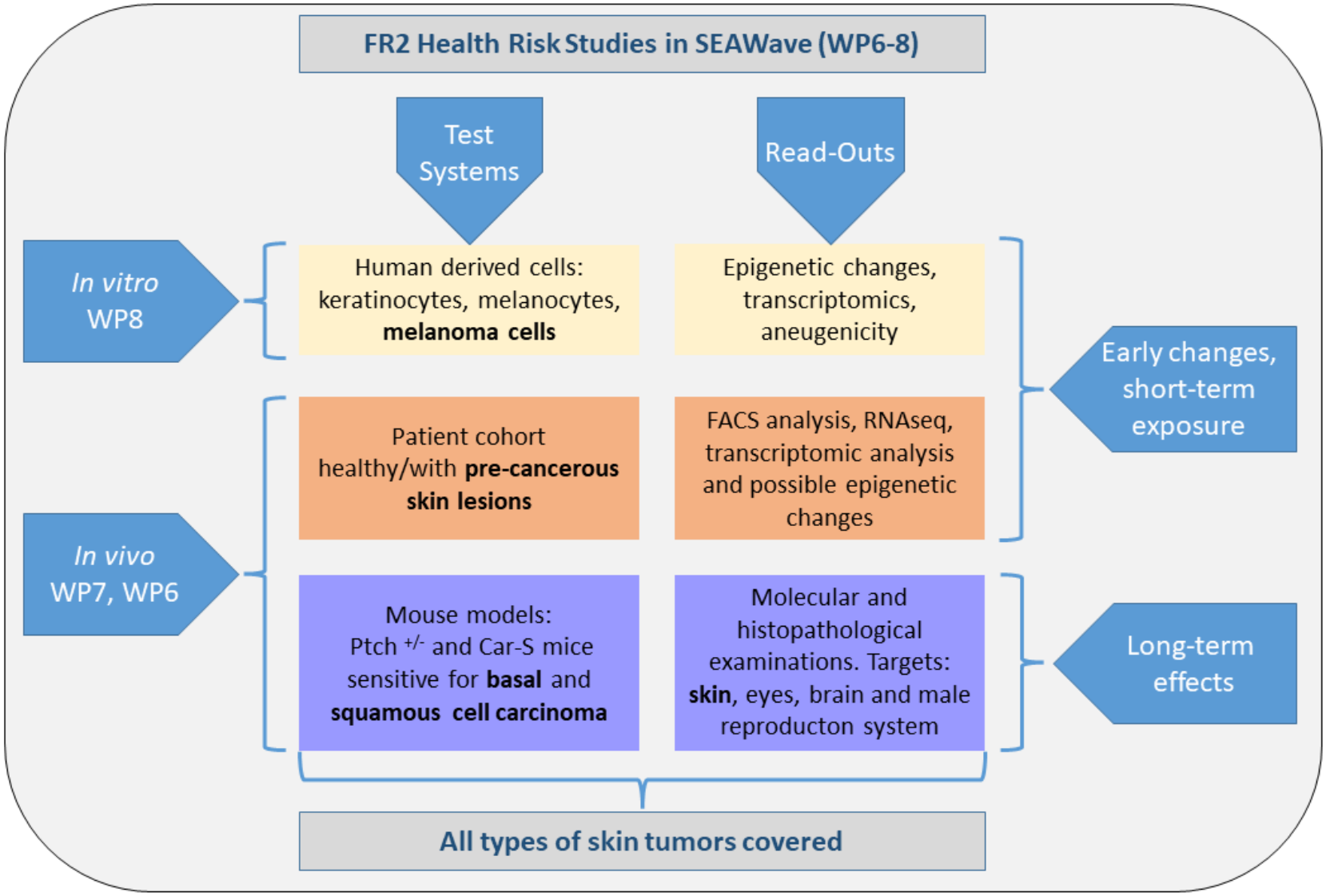
Introduction



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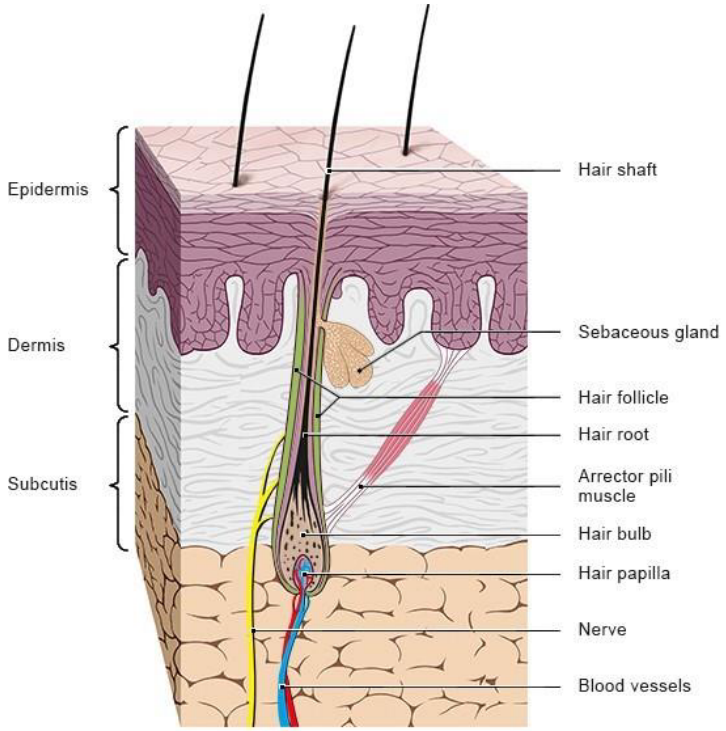
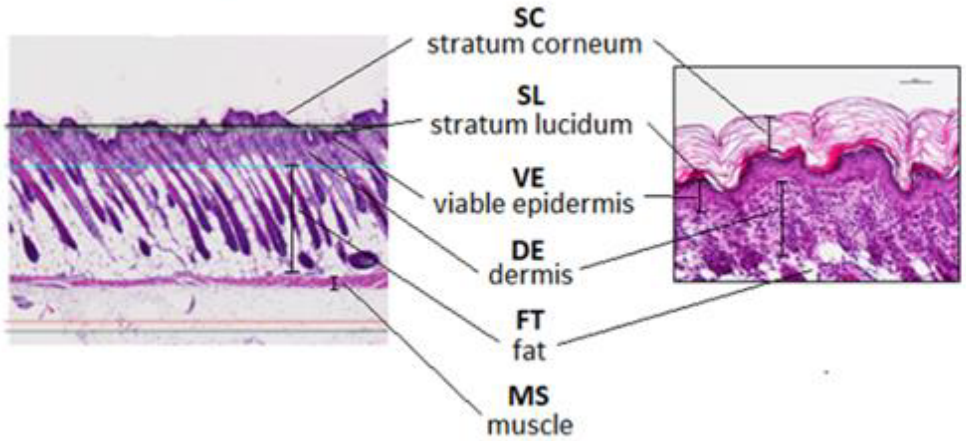
Skin anatomy





Mouse skin layers identification on an H&E stained sample

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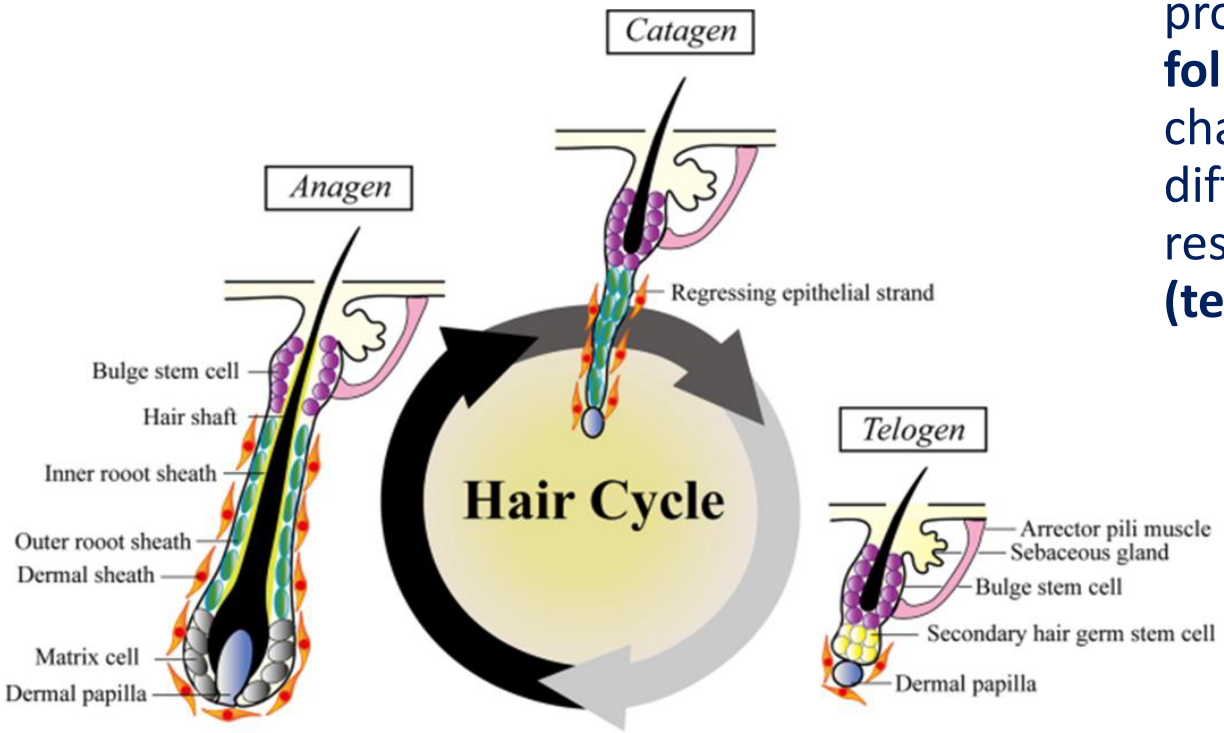
Time variability – Hair cycle

Hair growth is a dynamic process and can be divided in **three distinct phases**.



Active hair growth (anagen) is accompanied by hair shaft elongation, melanogenesis, and by massive keratinocyte proliferation, whereas **hair follicle regression (catagen)** is characterized by terminal differentiation and apoptosis, resulting in the **resting stage (telogen)**.

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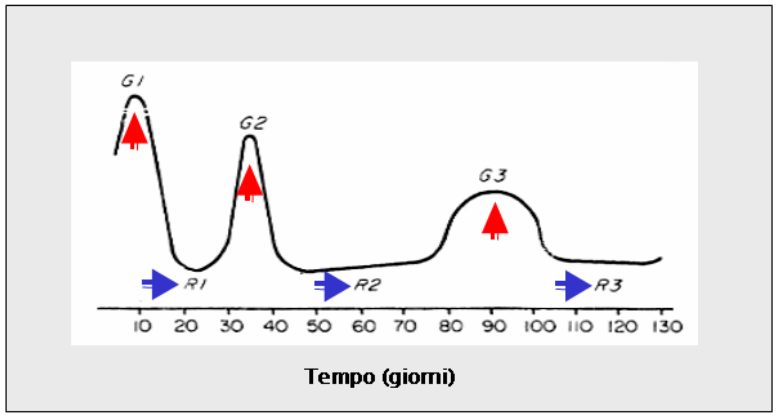
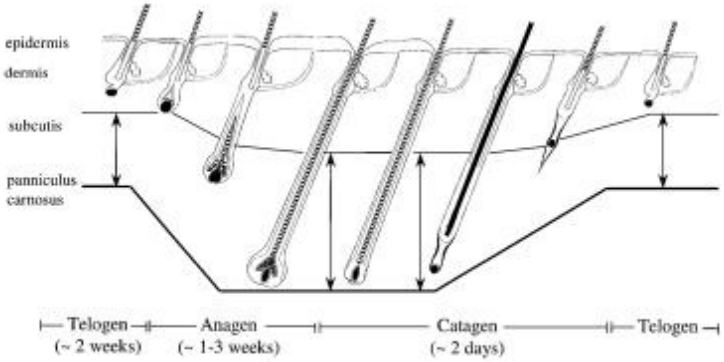
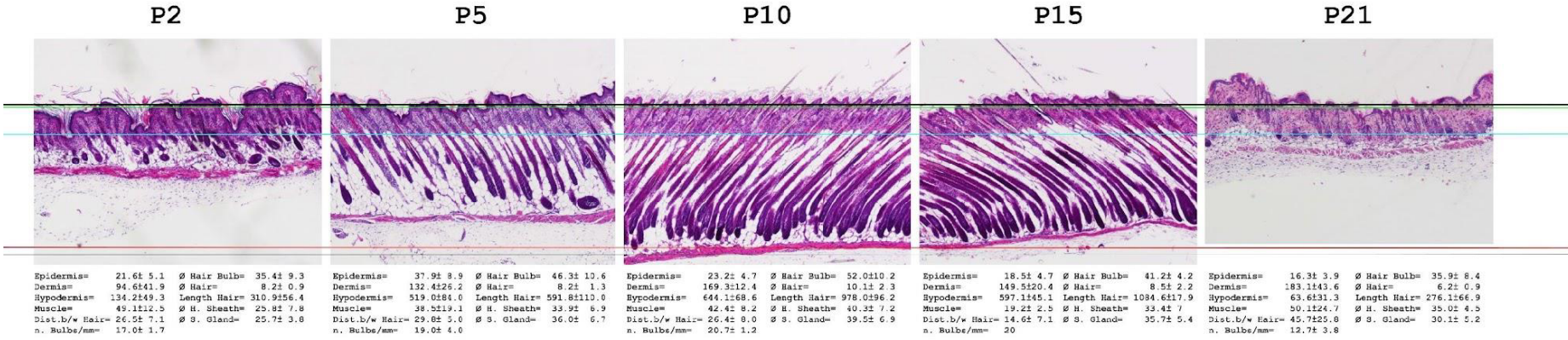
Time variability – Hair cycle

Hair cycle is a periodic phenomenon that lasts approximately **21 days**.



Significant **variations of skin layers' thickness** occur throughout a hair cycle.





Early anagen | Mid anagen | Late anagen | Catagen | Telogen

N=3 mice X 4 measurements = 12 measurements for each time point

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Time variability – Dielectric parameters

- At mmWave frequencies (e.g., 27.5 GHz) EMF interaction with tissues results mostly from free water polarization (γ-dispersion)
- Water content of tissues changes with age
- Total Body Water (TBW) and its variations with age is known for mice from the literature (*Bailey et al, 1960*)
- Assuming that the water content of each skin layer varies according to TBW, except for Keratinized Stratum = Stratum Corneum + Stratum Lucidum (which is not considered variable with age here) , we can evaluate dielectric properties variations with age by applying Lichtenecker's formula

$$\dot{\varepsilon}_r = \varepsilon_{rw}^{\frac{\alpha-\alpha_A}{1-\alpha_A}} \cdot \varepsilon_{rA}^{\frac{1-\alpha}{1-\alpha_A}} \left(1 - j\frac{1}{\omega\tau}\right), \quad \alpha=\rho\cdot TBW$$

where ε_r : complex permittivity of tissue, ε_{rA}: complex permittivity at age A, ε_{rw}: complex permittivity of water, α: hydrated rate, ρ: mass density

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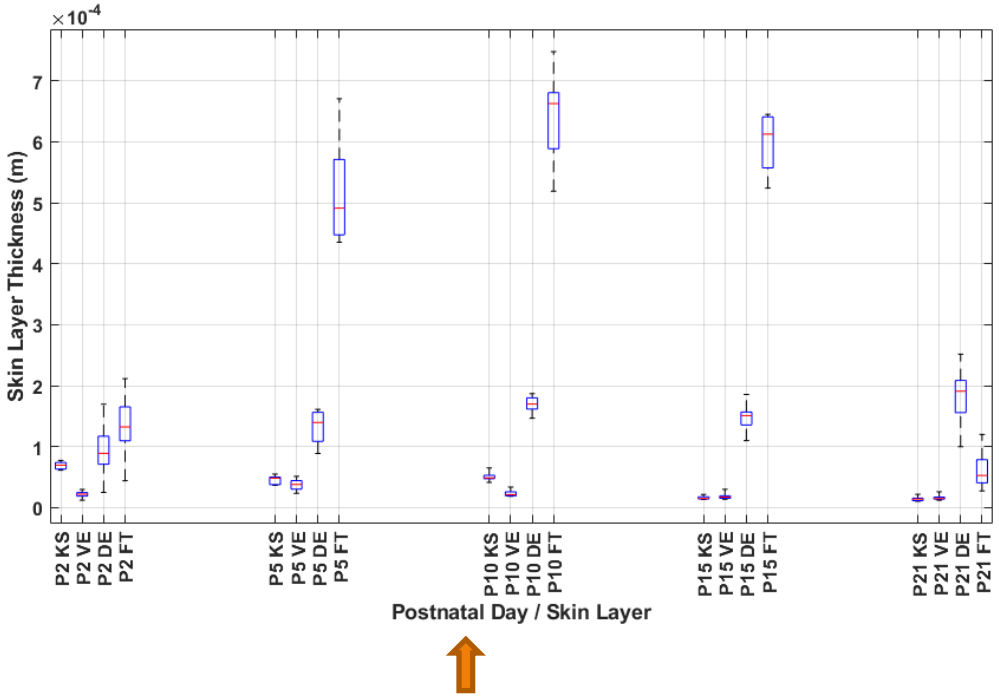
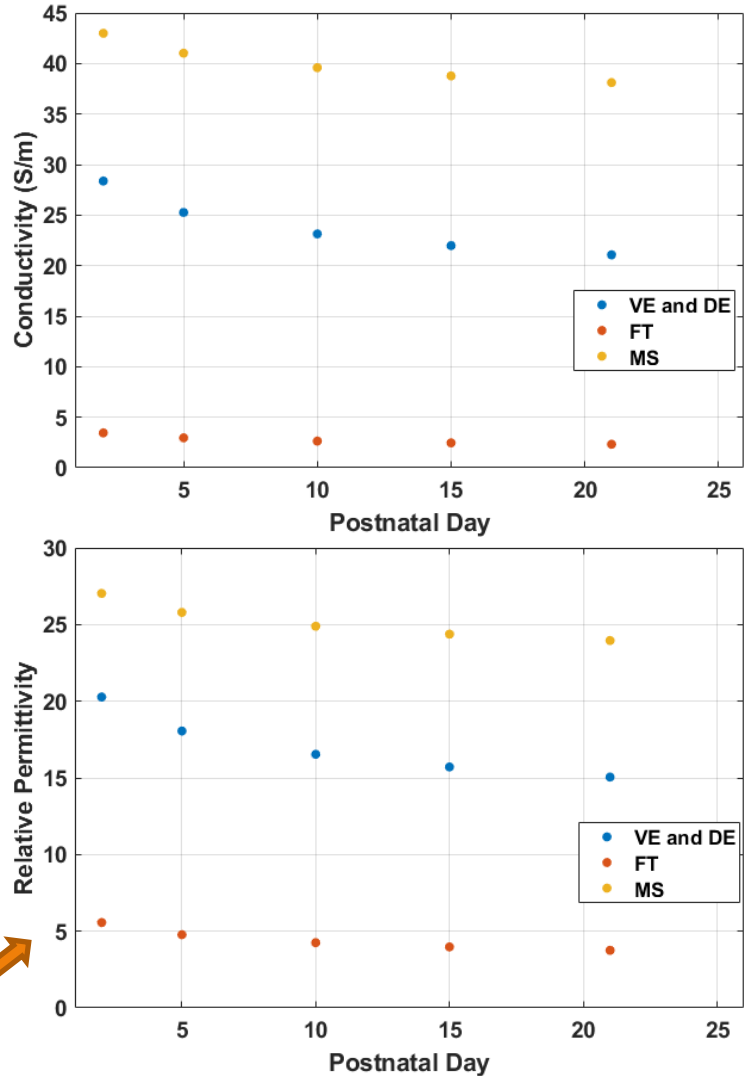
Time variability – Evaluated variability during first hair cycle (P2-P21)



Skin layer thickness varies significantly during a hair cycle, esp. for fat (FT) layer

Dielectric properties values reduce during the first days of life and tend to a constant value afterwards



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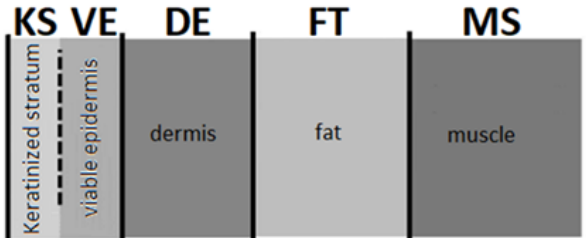
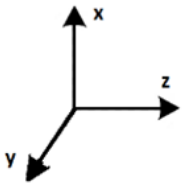
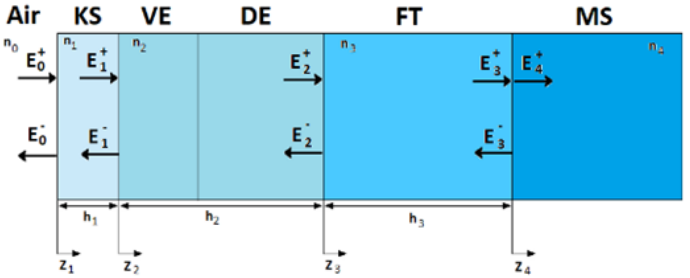
Computational model – Analytical solution







Considered mouse skin layers

- KS (Keratinized stratum= Stratum Corneum + Stratum Lucidum)
- VE (Viable Epidermis)
- DE (Dermis)
- FT (Fat)
- MS (Muscle)

- E and H field values were calculated analytically
- TEM plane wave incidence ($1W/m^2$) is considered along z-axis
- VE and DE share the same dielectric properties
- MS is considered the terminating layer (reflections from tissues underlying muscle layer are not considered)

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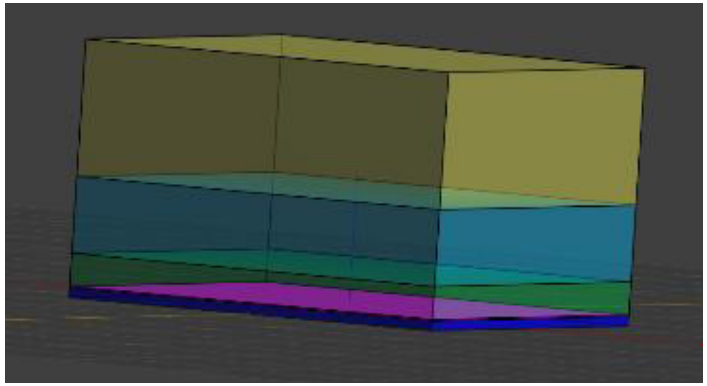
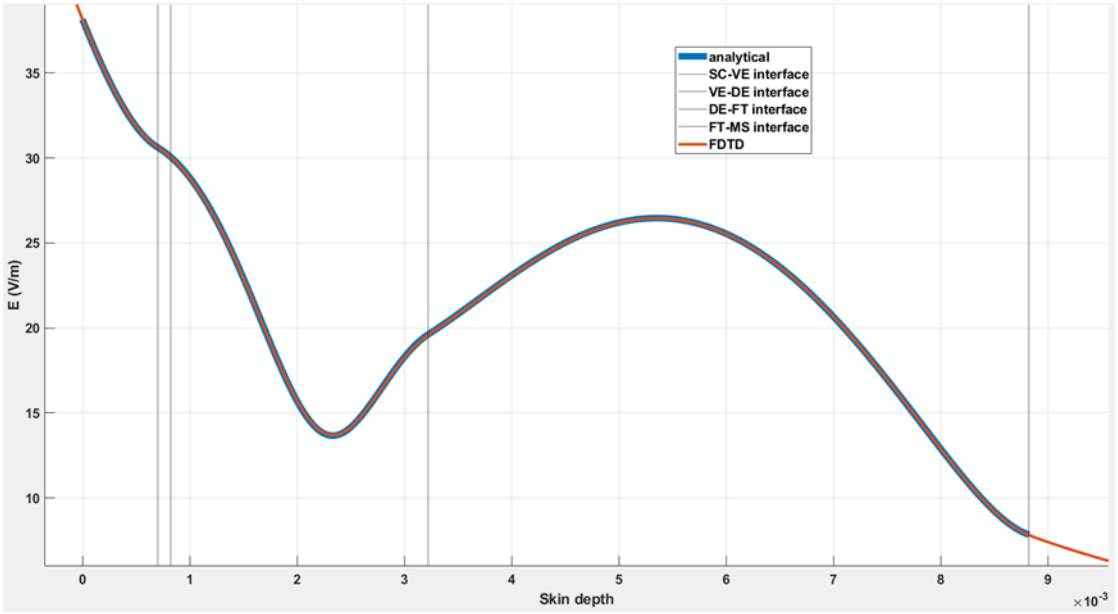
Computational model – Numerical solution (Sim4Life)



- MS (yellow)
- FT (cyan)
- DE (green)
- VE (pink)
- KS (blue)



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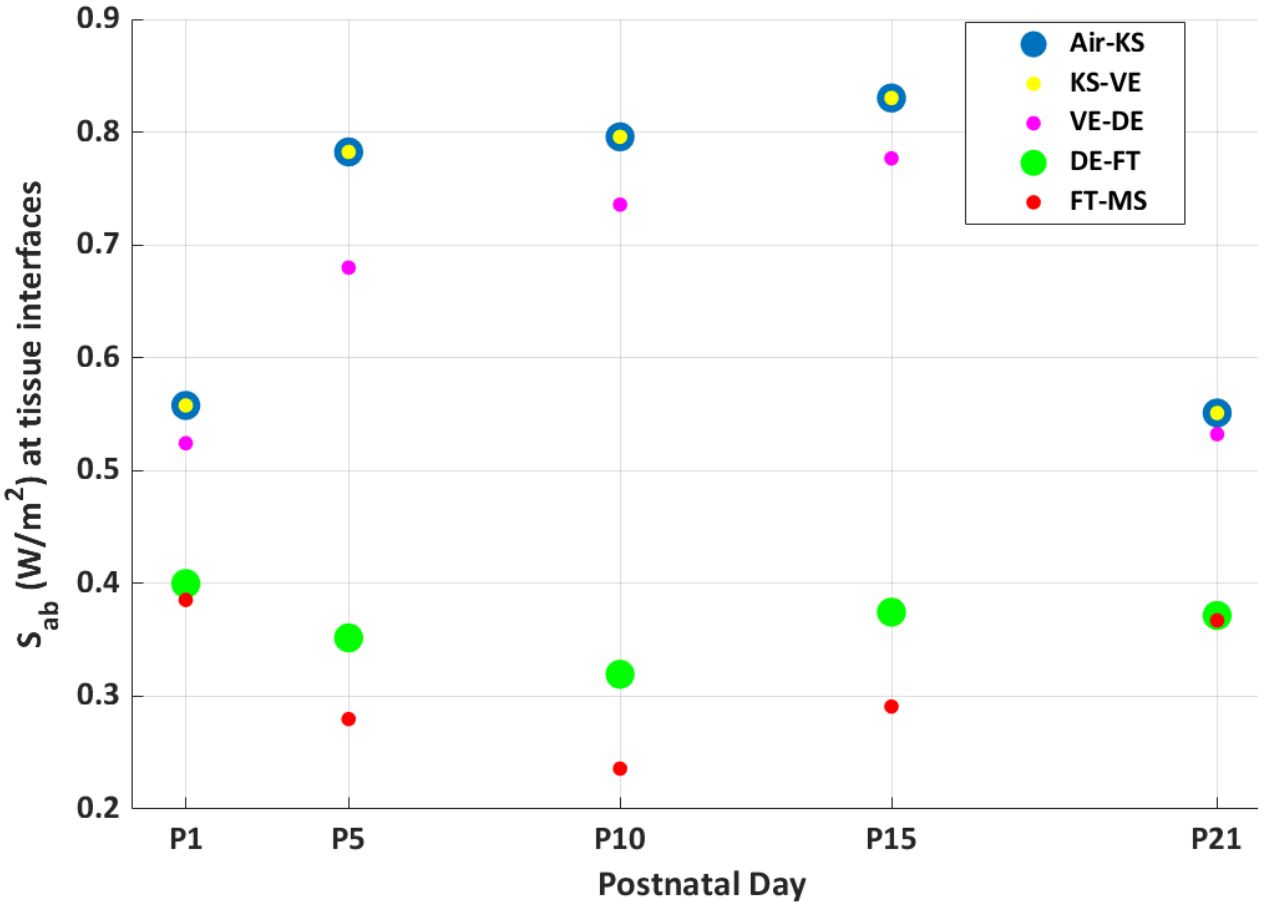
Results – APD at tissue interfaces

$$S_{ab} = \iint_A Re[\boldsymbol{S}] \cdot \frac{d\boldsymbol{s}}{A} = \iint_A Re[\boldsymbol{E} \times \boldsymbol{H}^*] \cdot \frac{d\boldsymbol{s}}{A}$$



- A significant portion of power is reflected to air (up to 45%)
- Large variations between different postnatal days

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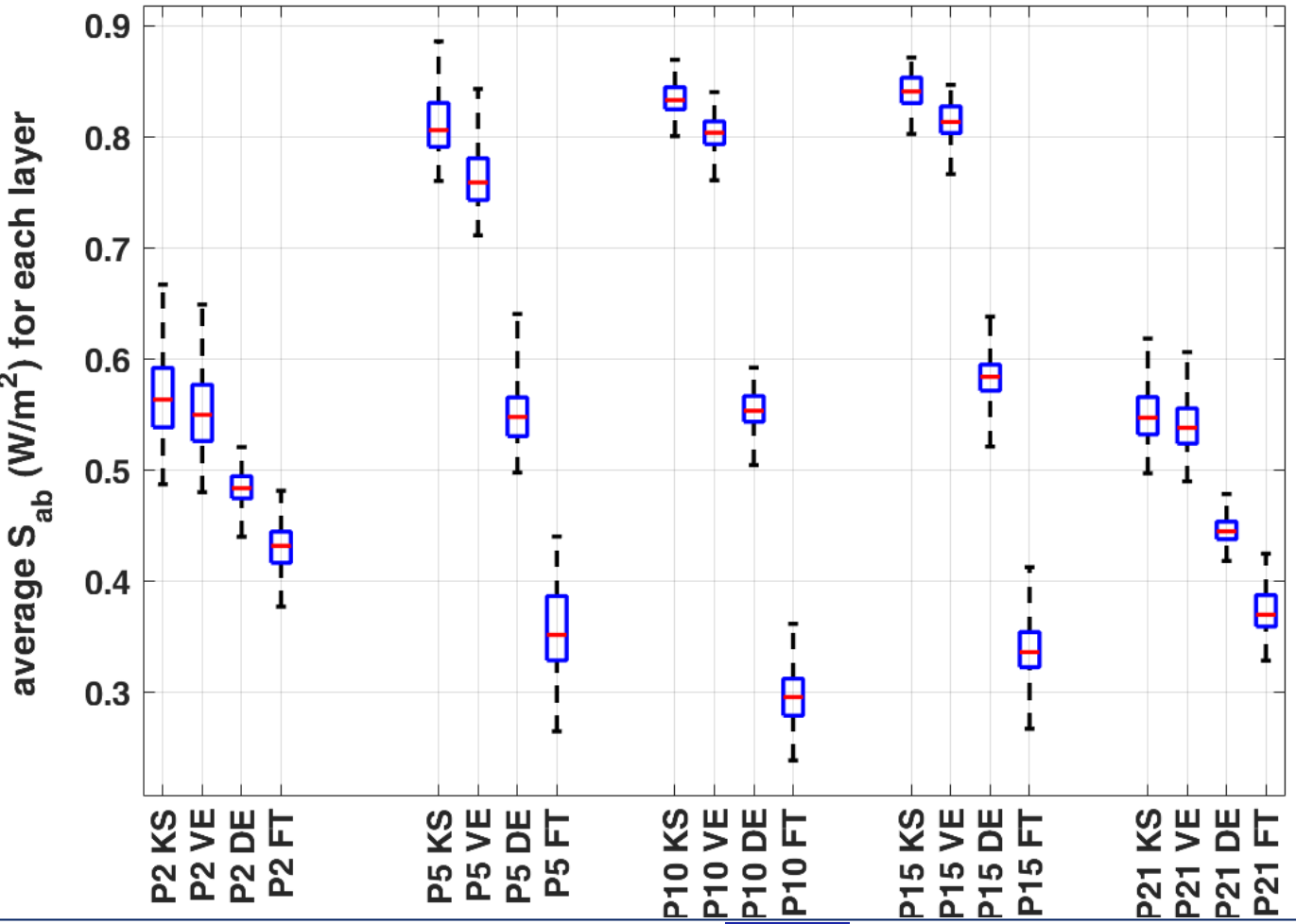
Results – APD average in each layer with postnatal day (layer thickness)

$$\overline{S_{ab}} = \frac{\int_{z_1}^{z_2} S_{ab}(z)dz}{\int_{z_1}^{z_2} dz}$$



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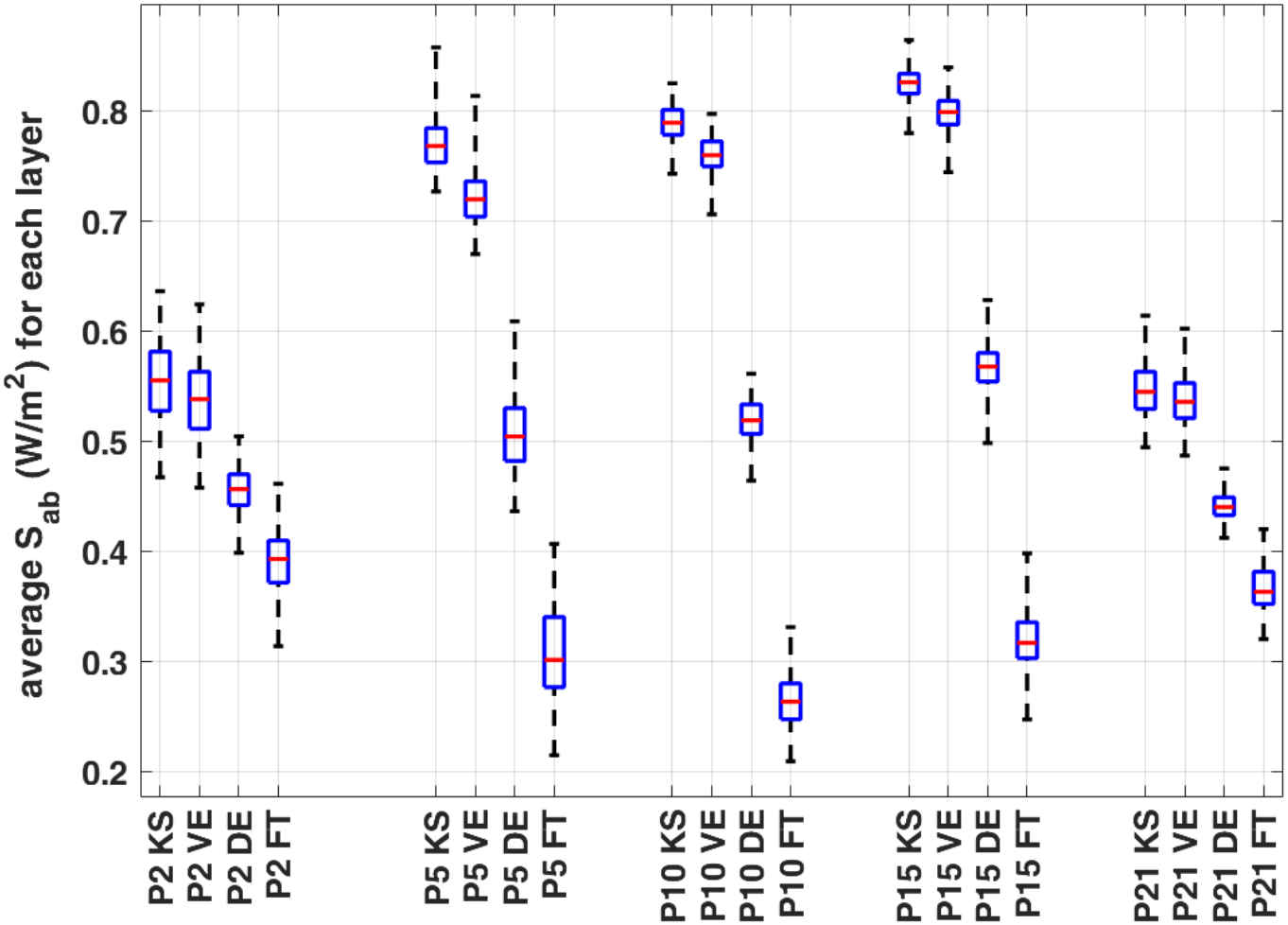
Results – APD average in each layer with postnatal day and TBW

$$\overline{S_{ab}} = \frac{\int_{z_1}^{z_2} S_{ab}(z)dz}{\int_{z_1}^{z_2} dz}$$



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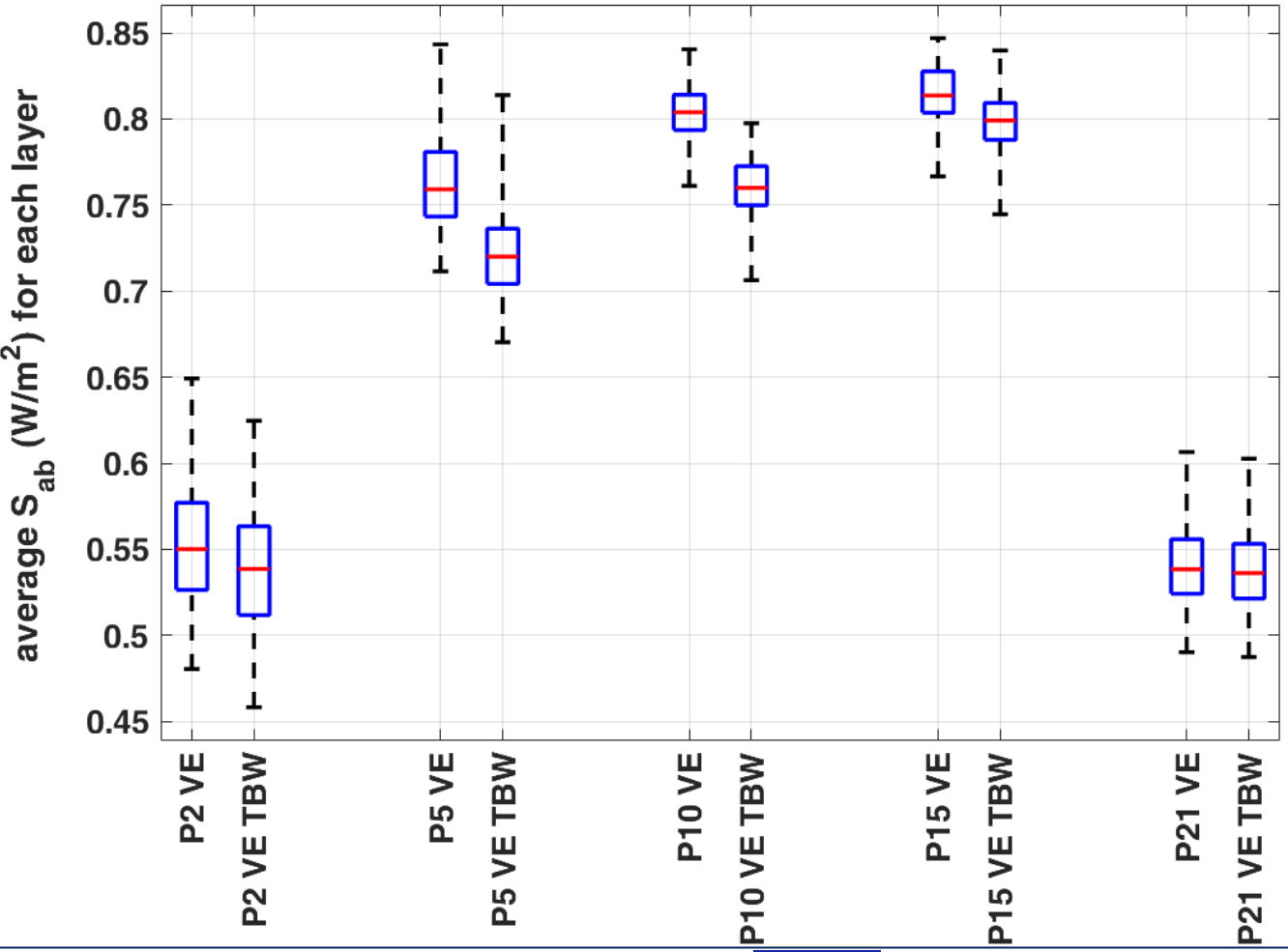
Results – APD average in viable epidermis

$$\overline{S_{ab}} = \frac{\int_{z_1}^{z_2} S_{ab}(z)dz}{\int_{z_1}^{z_2} dz}$$



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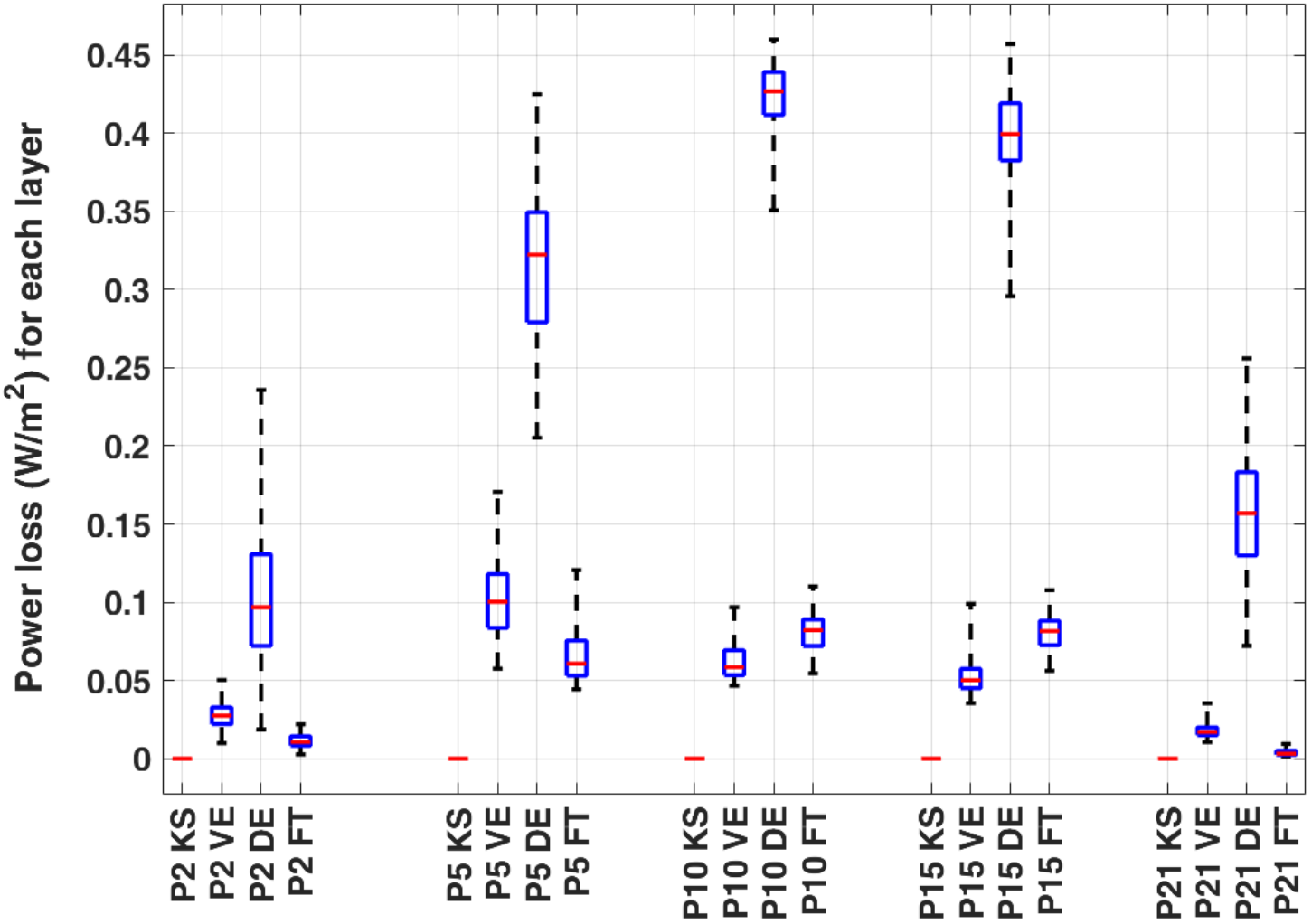
Results – Power loss for APD with postnatal day

$$PL = S_{ab}(z_2) - S_{ab}(z_1)$$



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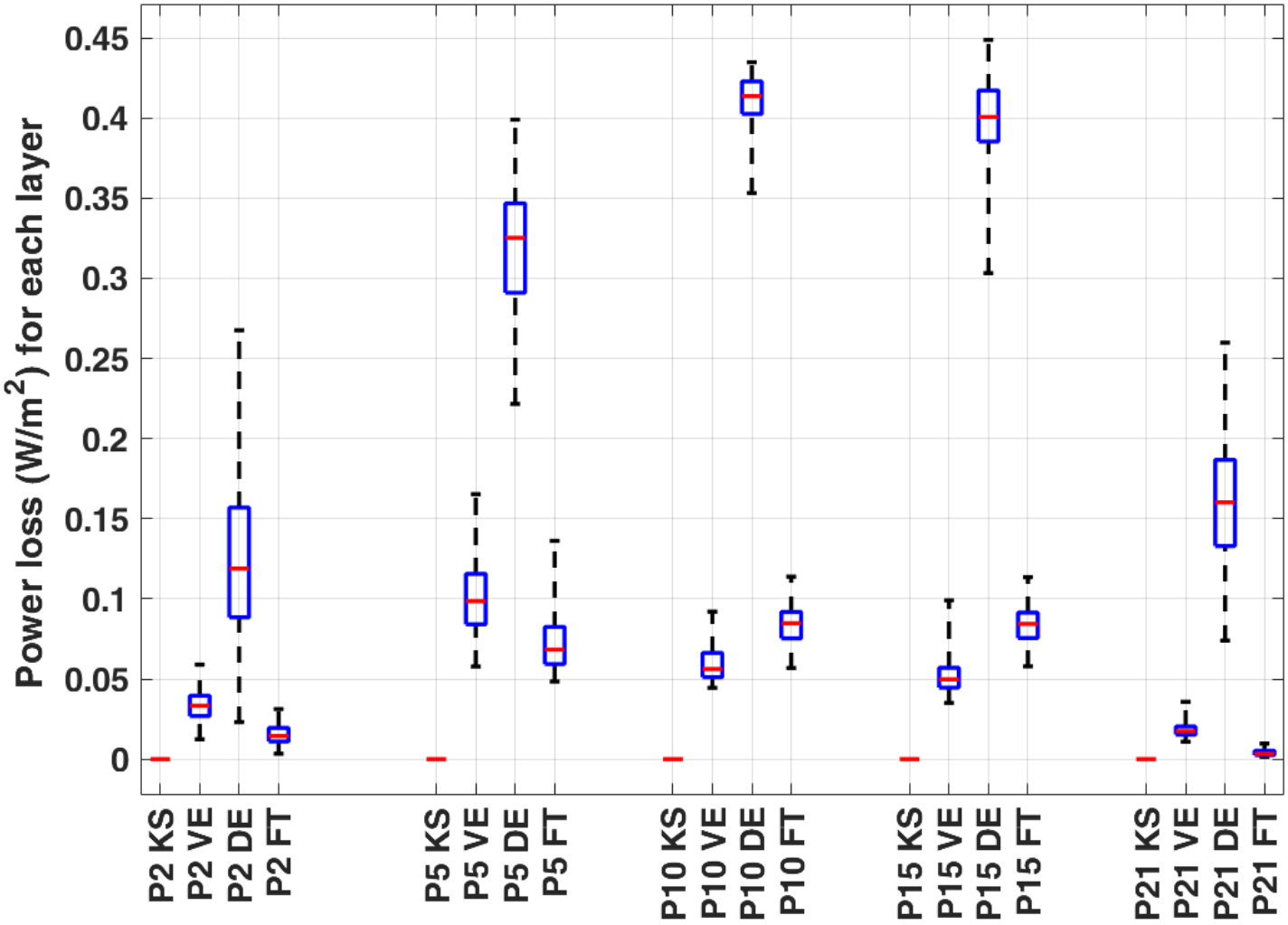
Results – Power loss for APD with postnatal day and TBW

$$PL = S_{ab}(z_2) - S_{ab}(z_1)$$



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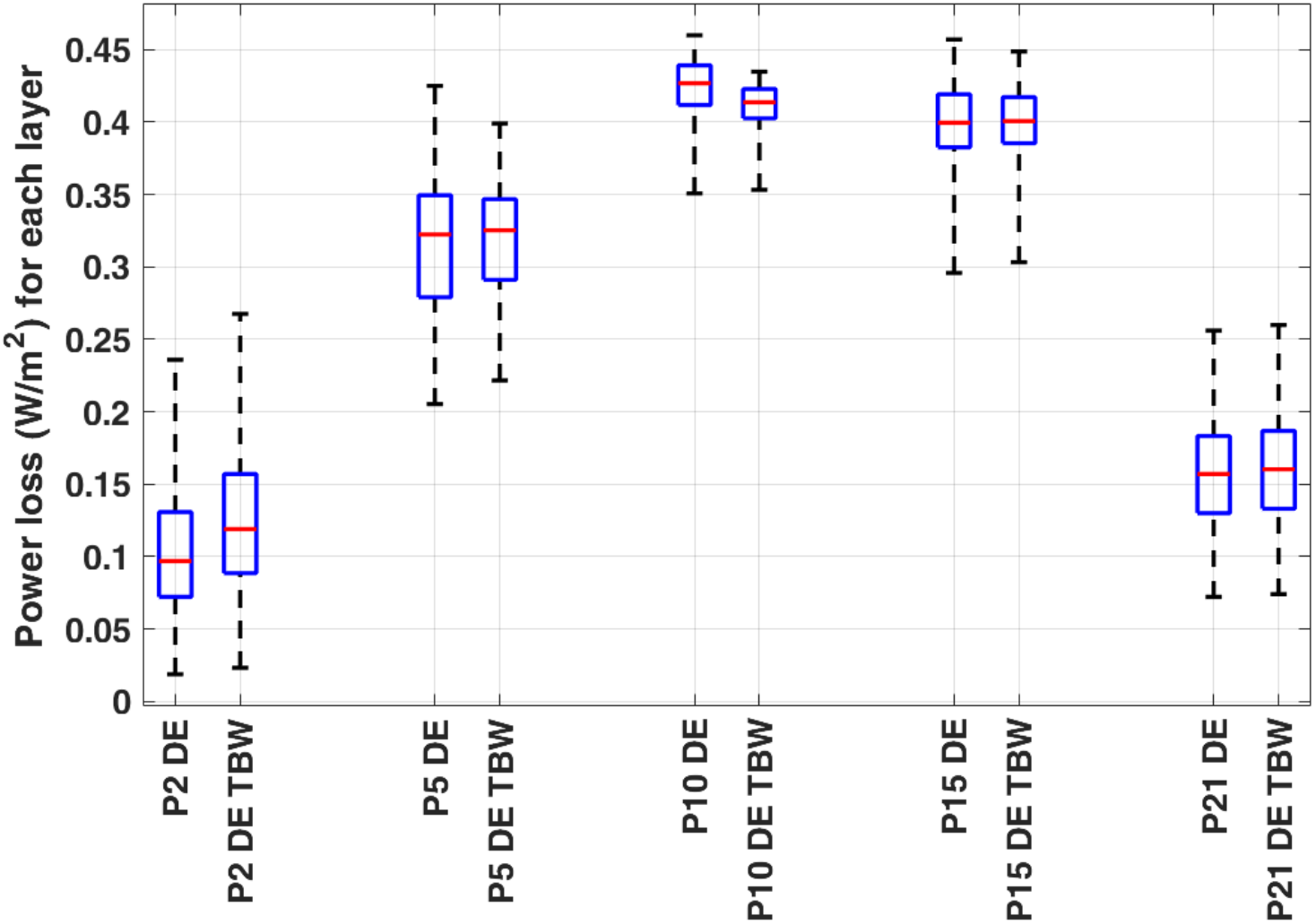
Results – Power loss for APD in dermis

$$PL = S_{ab}(z_2) - S_{ab}(z_1)$$



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Conclusions

- Skin is an organ with a highly complex and dynamic anatomy that changes in time (i.e., keratinization, hair cycle, TBW variations)
- The impact of this dynamic behavior of murine skin on dosimetry was evaluated during the first hair cycle (P2-P21) for
  - Skin layer thickness variation
  - Dielectric parameters variation due to changes in mouse TBW
- Both have significant impact on dosimetry, yet the impact from skin layers' thicknesses dominates
- The maximum APD deposited within any skin layer found is 0.45 W/m^2 (for 1 W/m^2 incident power density) during the first hair cycle (P2-P21)

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