

Numerical simulations in medical devices

Yael Yasur

Rotem Industries Ltd.

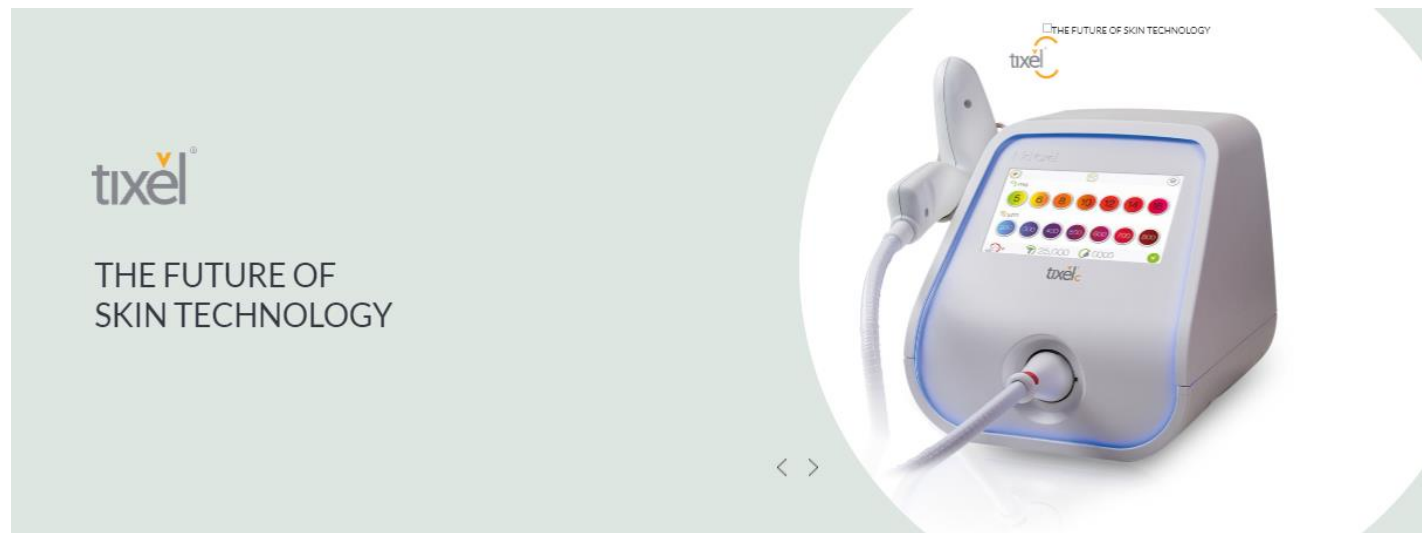
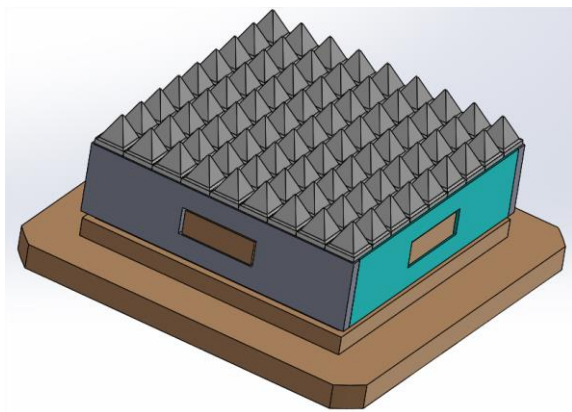
January 2021

Introduction

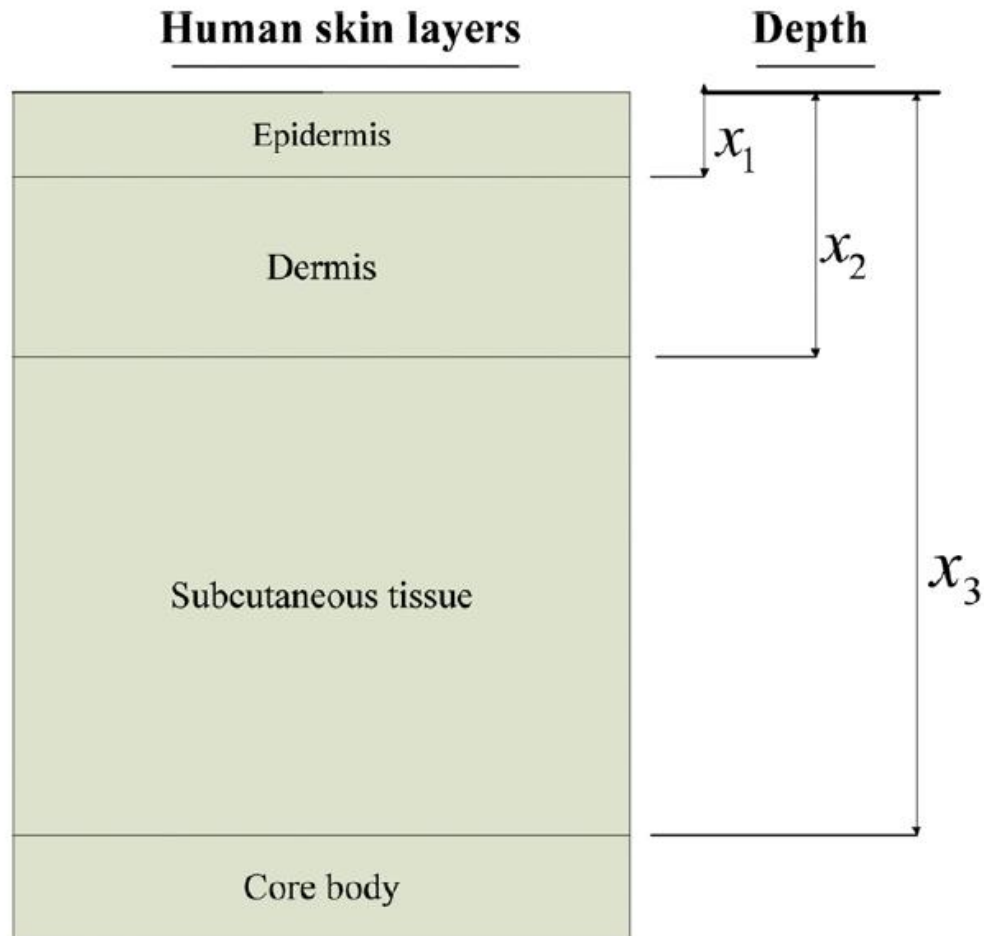
- Numerical simulations are a powerful tool for research and development.
- We will see a few projects of developing medical devices, involving numerical simulations.
- Novoxel Company developed the Tixel[®], a unique medical device for skin aesthetic and medical treatments.
- Dermafence is a startup company develops new formulations for treatment of skin burns.
- The team of Prof. D. Katoshevski from BGU and Dr. (MD) Yuval Cavari from Soroka hospital is collaborating with Dr. (MD) Iris Little and Prof. Effie Gutmark from U. of Cincinnati for developing a device for un-blocking and removing secretions from airways (DURSA), which is based on Oscillating flow combined with acoustics.

Novoxel

מכשיר לטיפול בעור הפנים



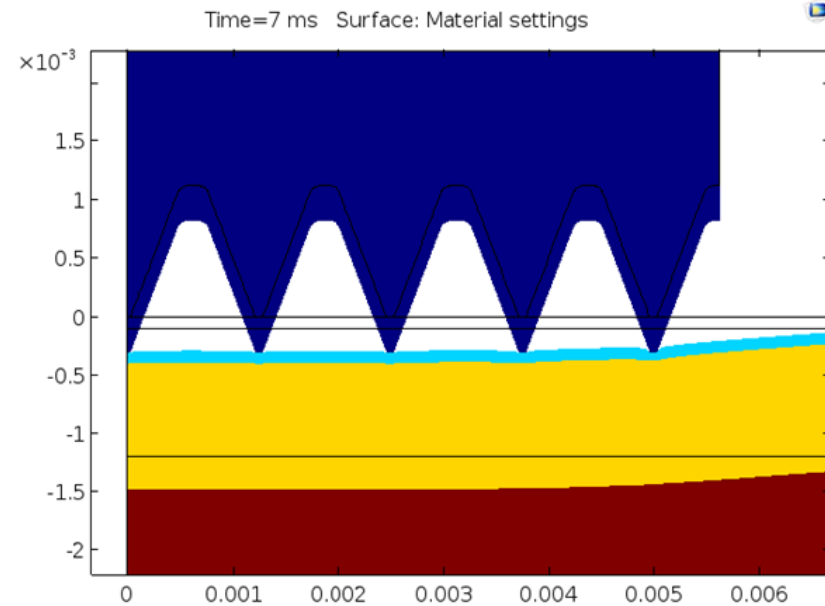
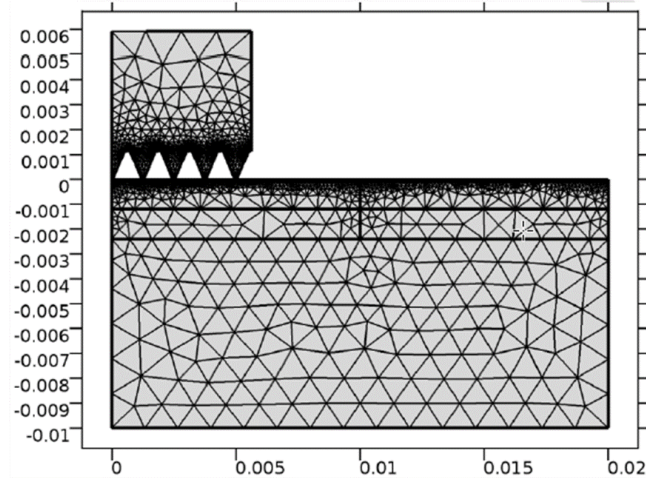
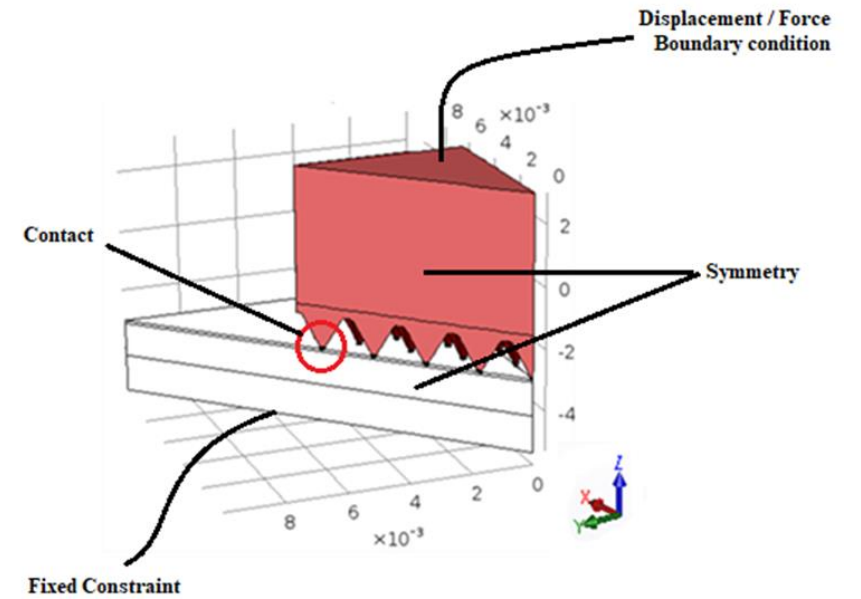
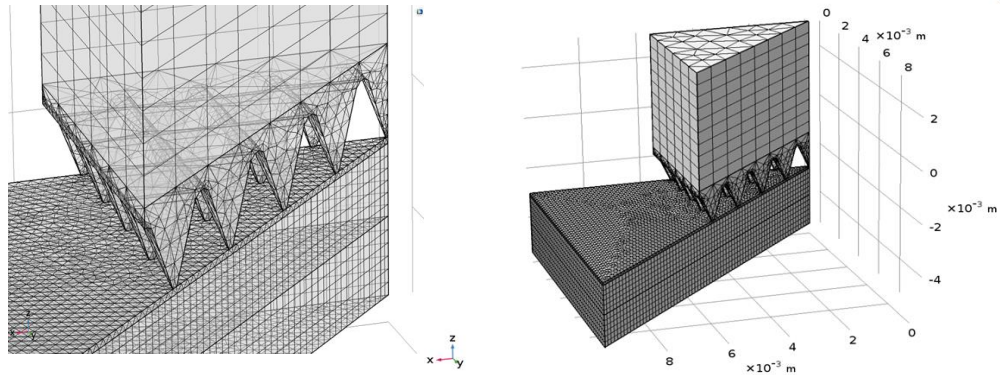
Skin layers



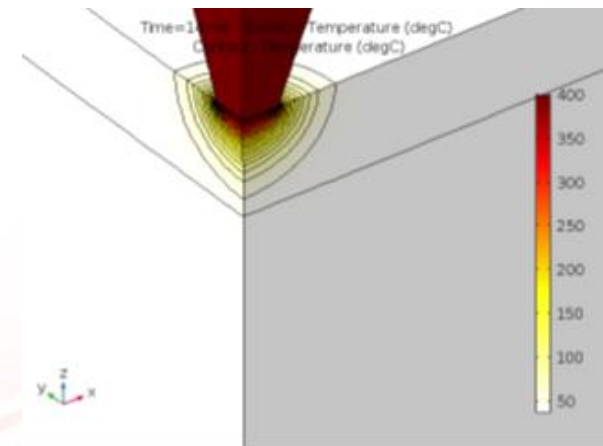
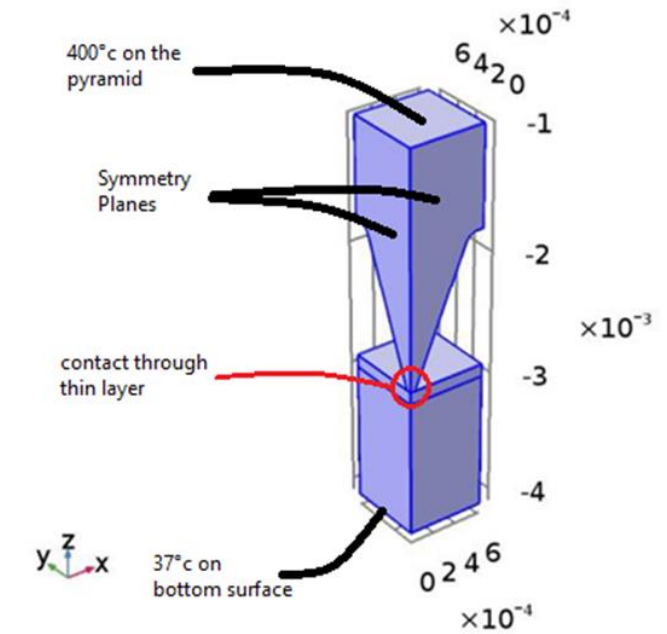
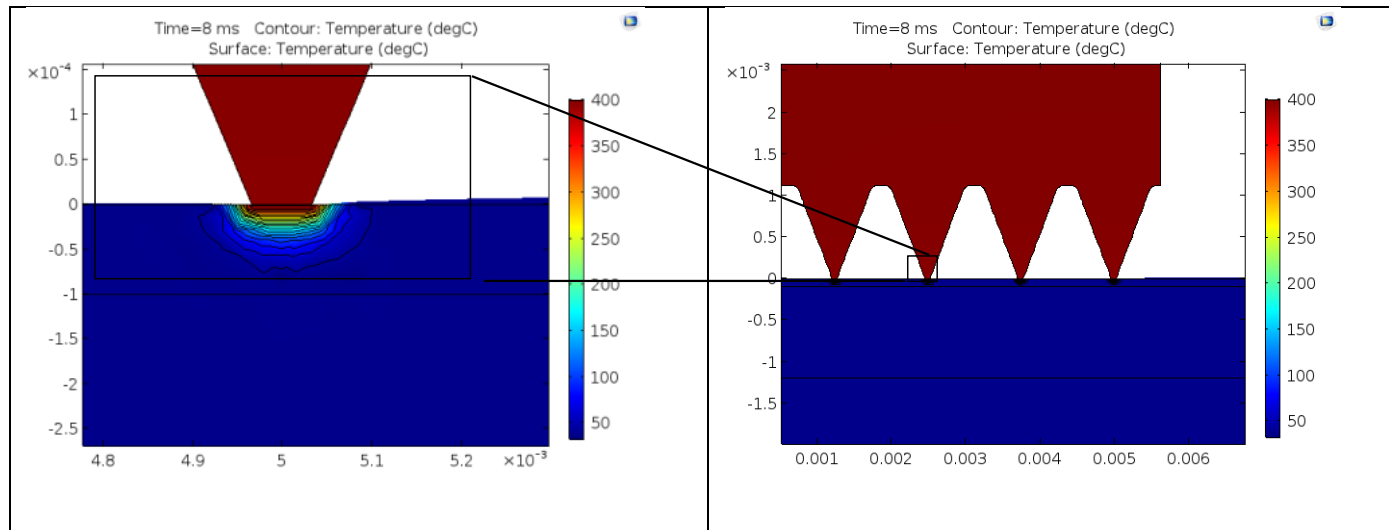
- אפידרמיס $> 0.1\text{mm}$
- דרמיס כ- 1.5mm
- שכבה תת עורית $3\text{-}4\text{mm}$

Figure 1. Schematic diagram of three-layer skin.

Mechanical analysis



Thermal analysis



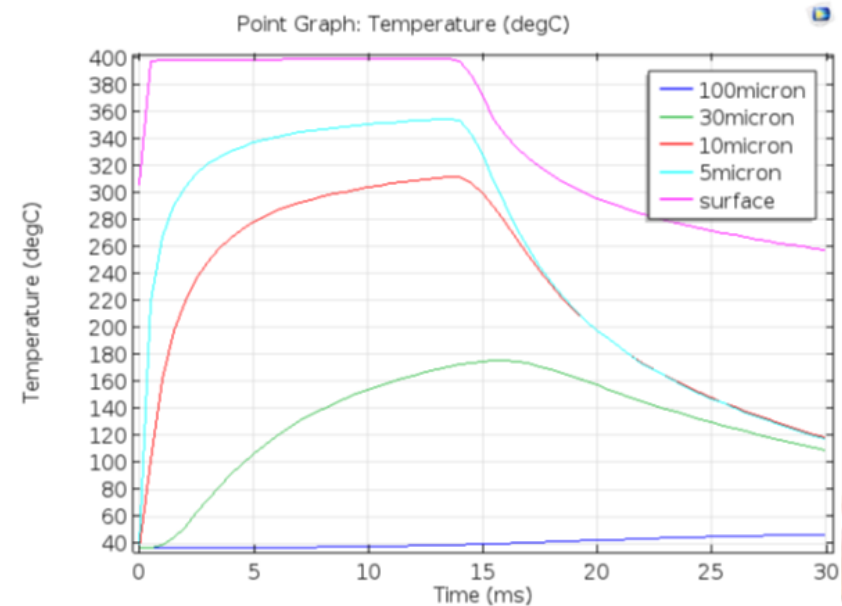
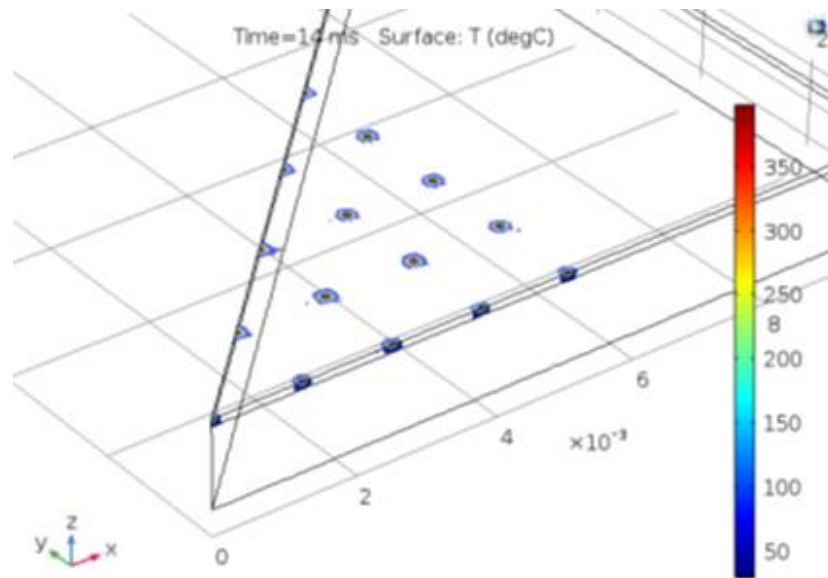
$$\rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{ted}$$

$$\mathbf{q} = -k \nabla T$$

Heat flux calculations

$$\text{heat_flux} = \iint_{\text{contact}} (\text{normal total heat flux}) dA$$

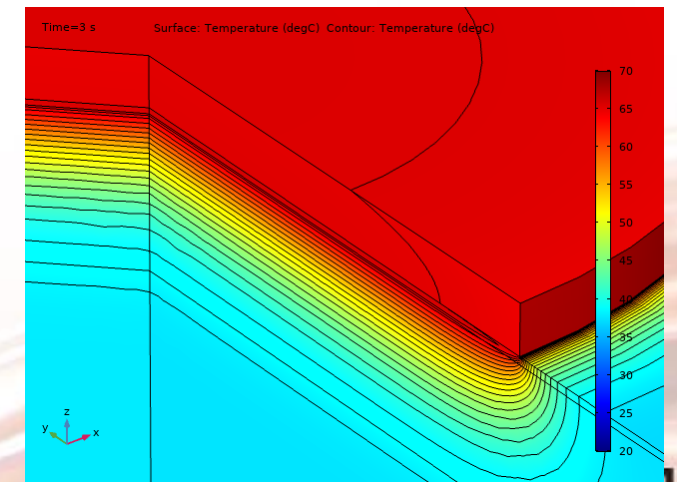
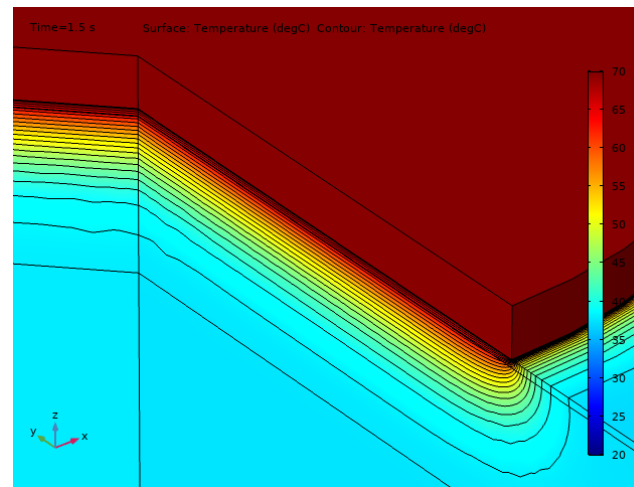
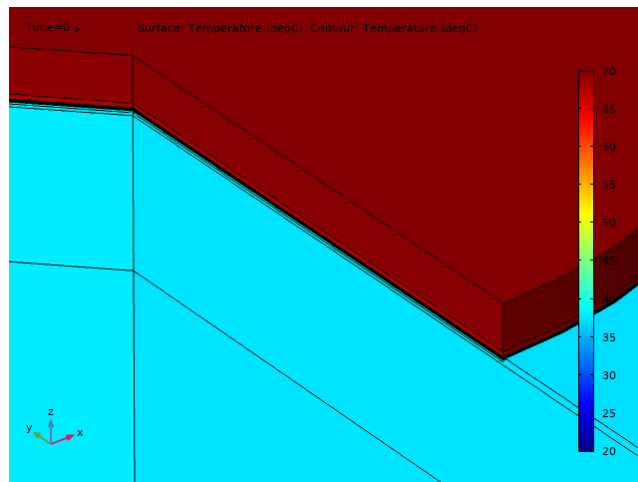
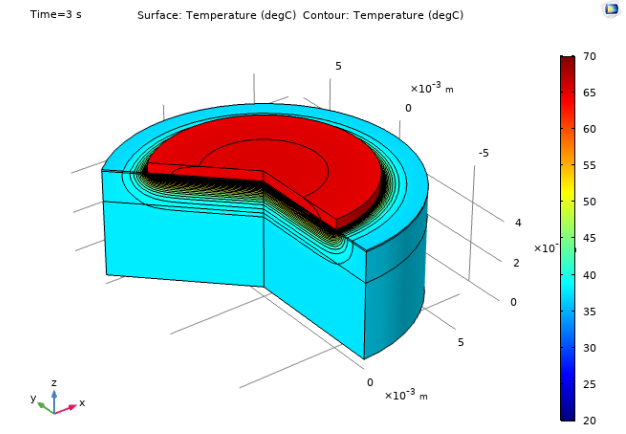
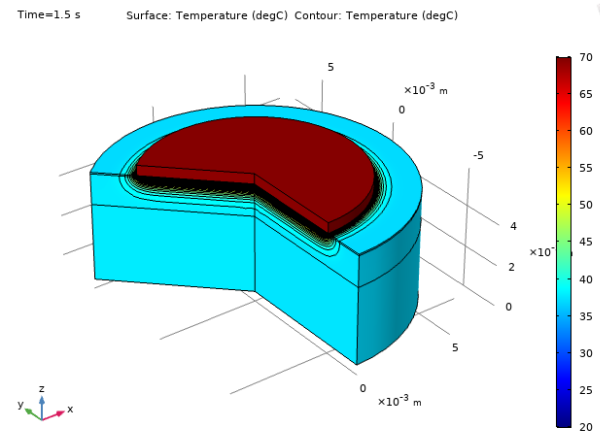
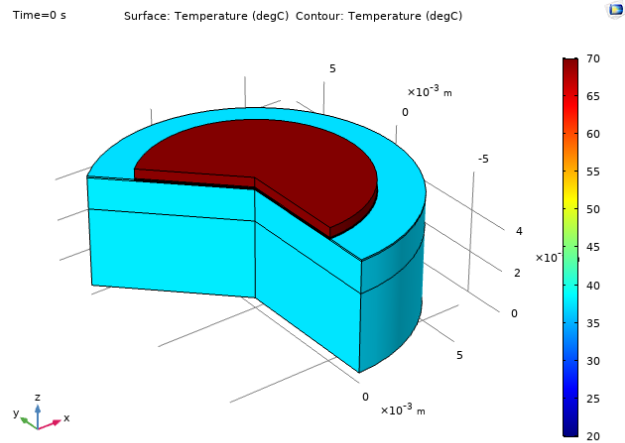
$$\text{total_Q} = \int_0^t (\text{heat_flux}) dt$$



Relaxation time vs. tissue depth after 14ms pulse

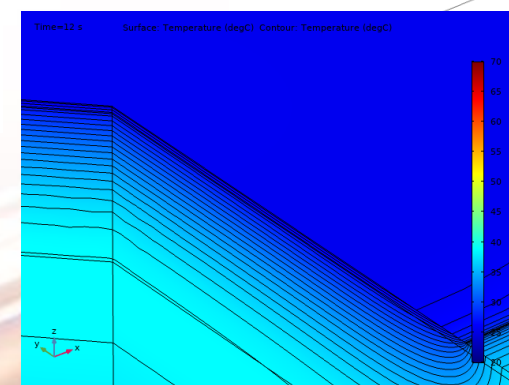
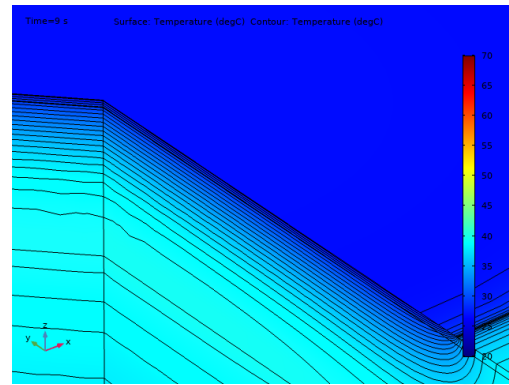
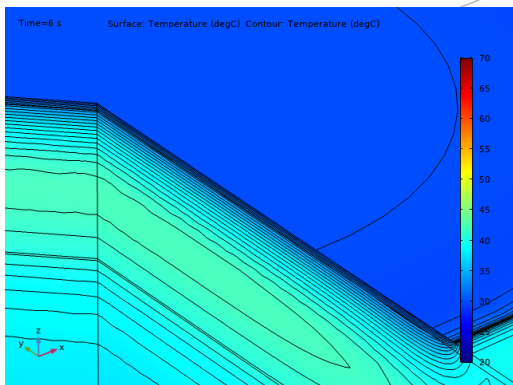
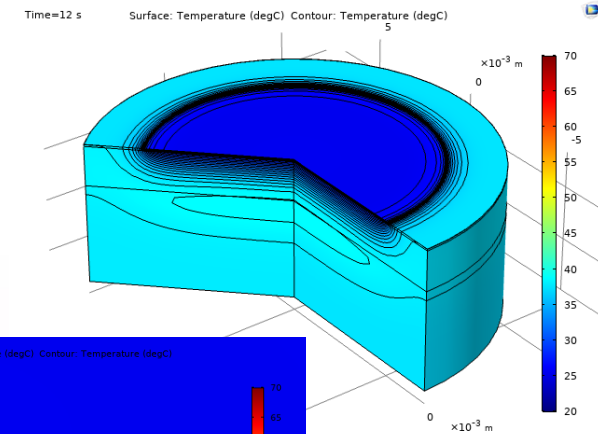
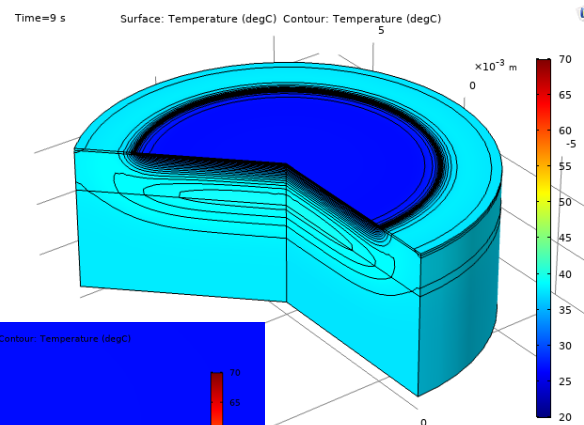
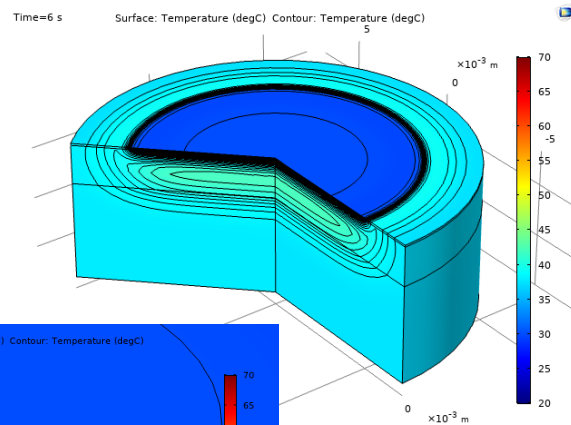
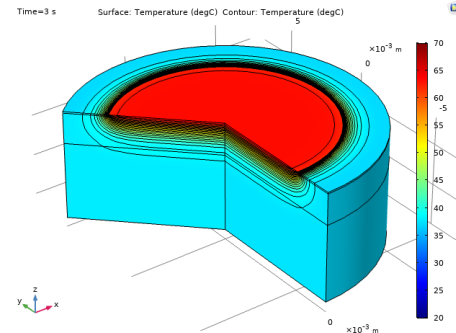
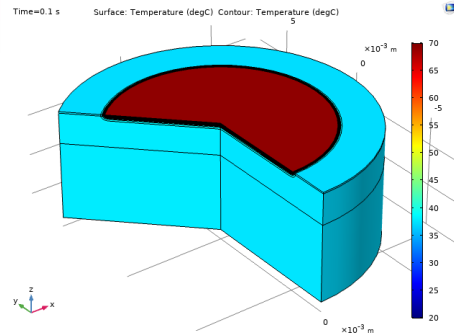
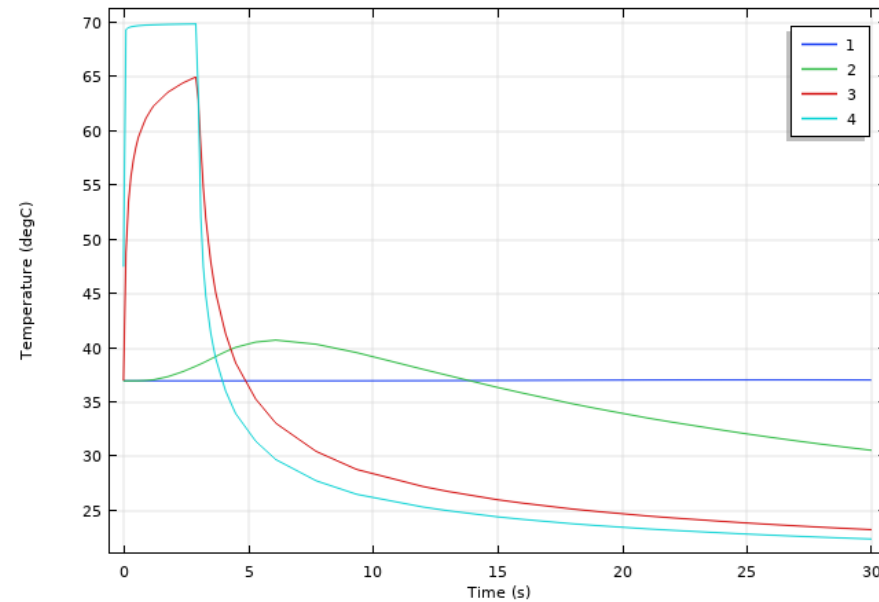
ניתוח תרמי של כווייה ותכשירי טיפול בכוויות
Dermafence

שלב יצירת הכווייה

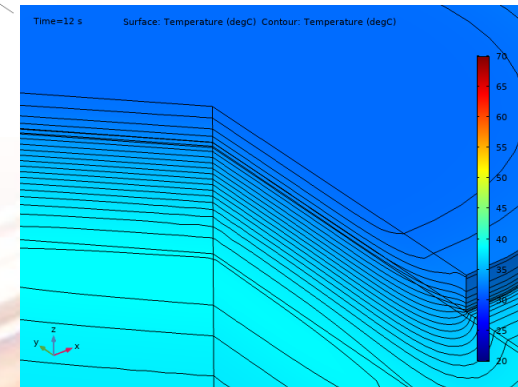
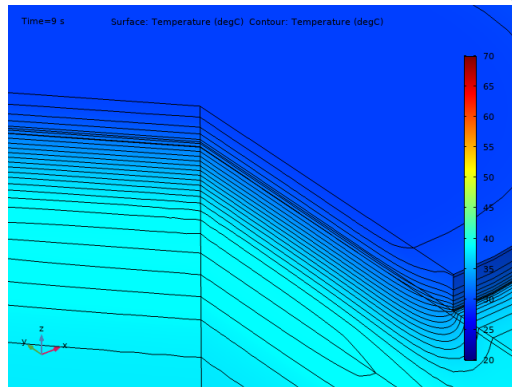
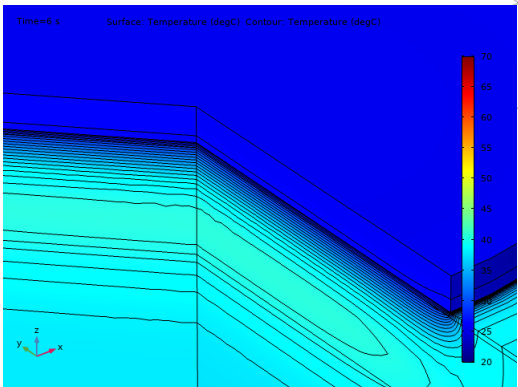
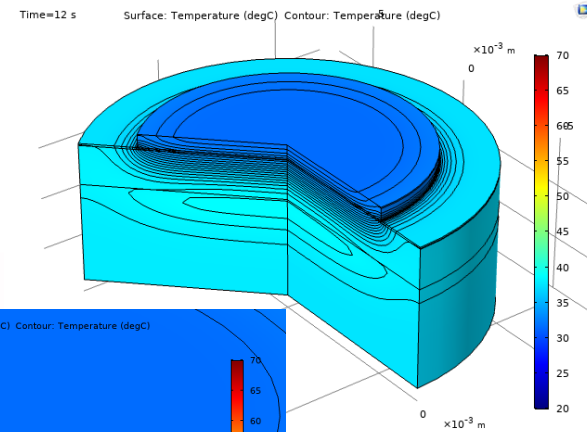
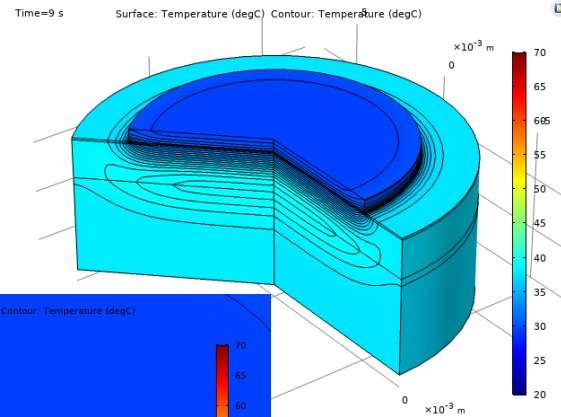
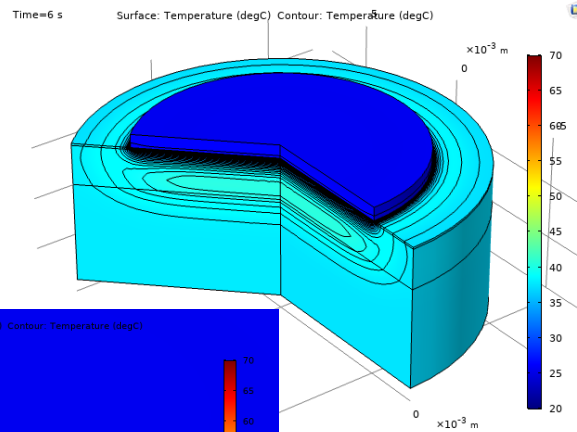
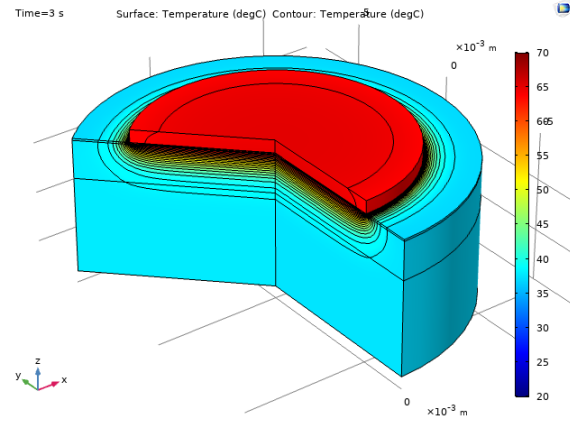
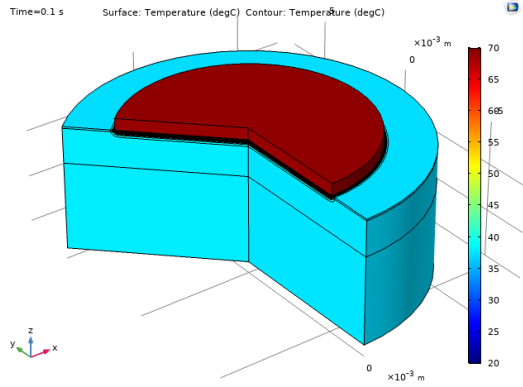


Water flow cooling

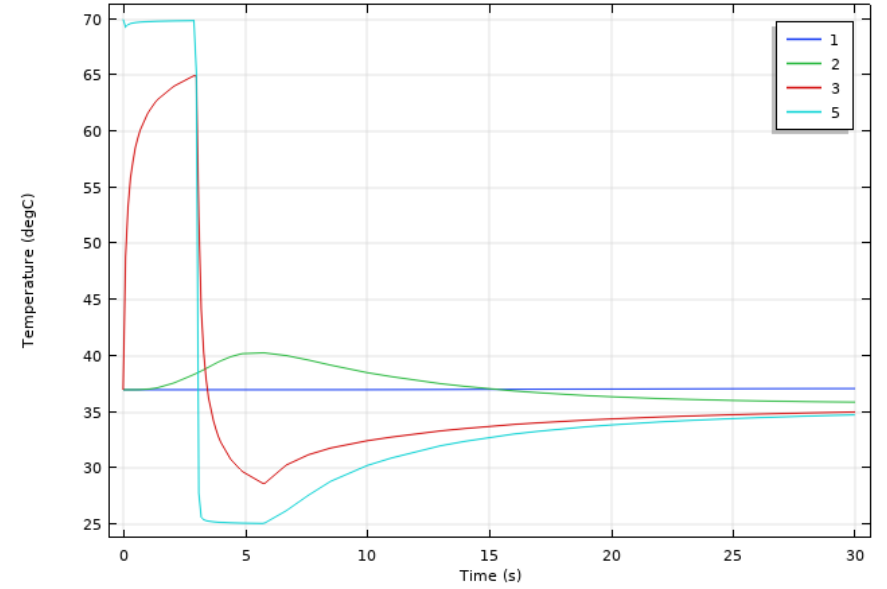
Point Graph: Temperature (degC)



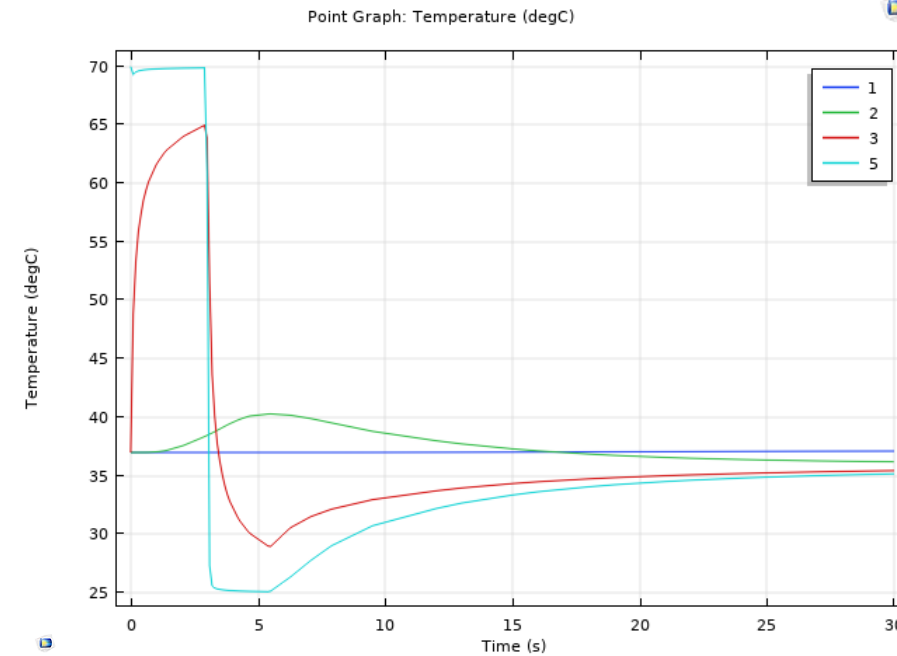
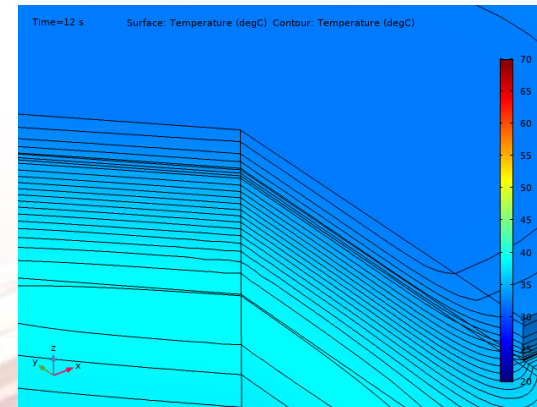
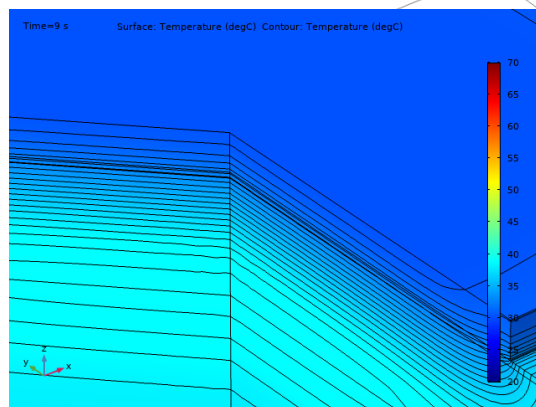
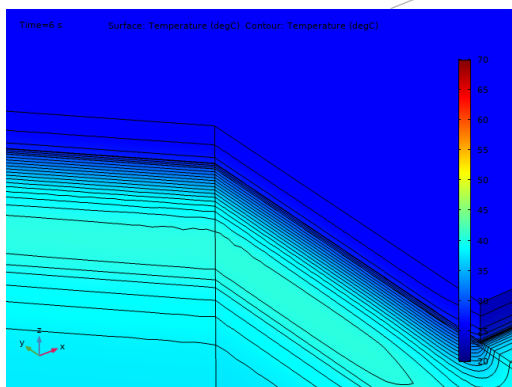
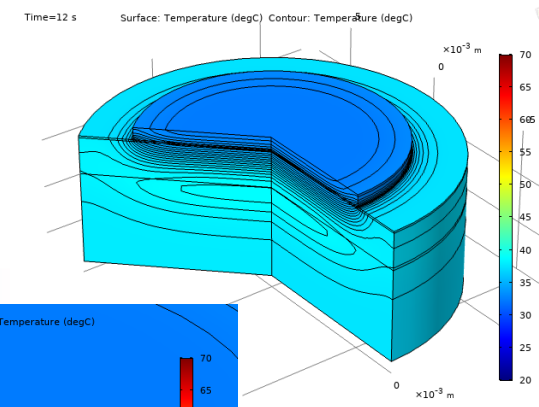
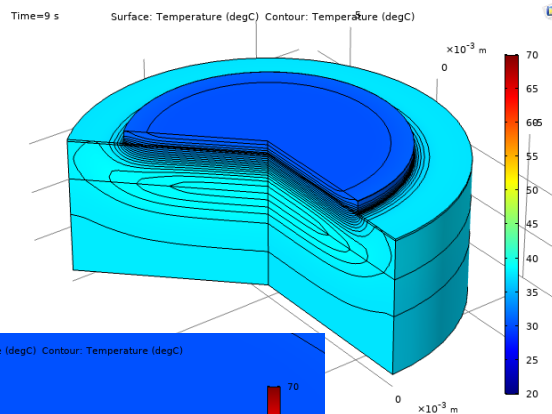
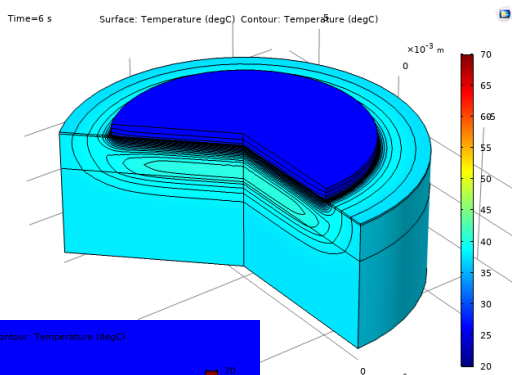
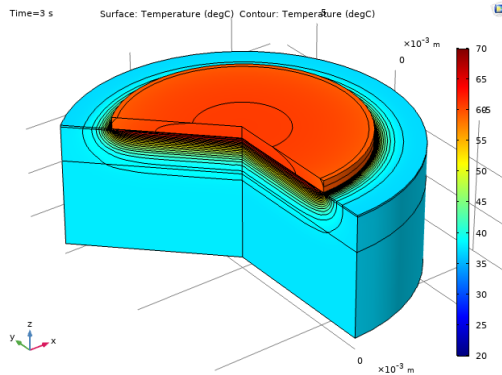
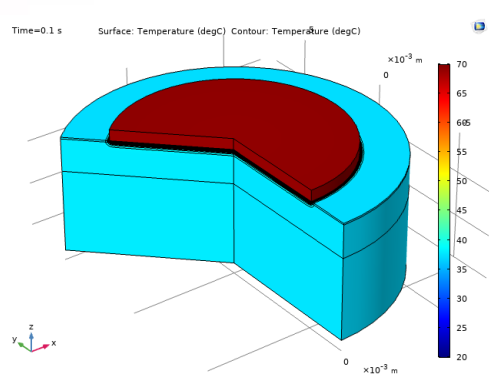
Dermafence F44



Point Graph: Temperature (degC)

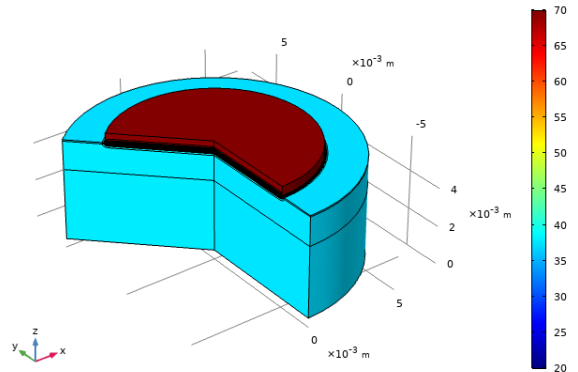


Dermafence F20

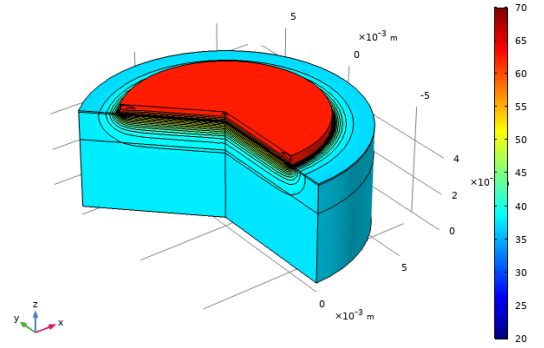


Silverol

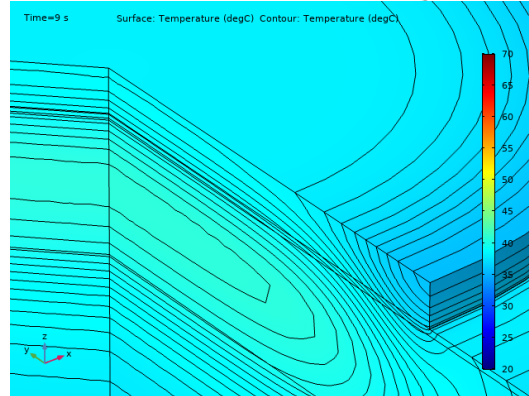
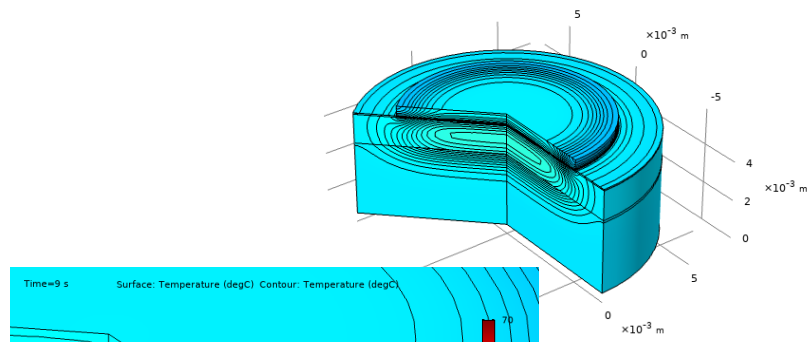
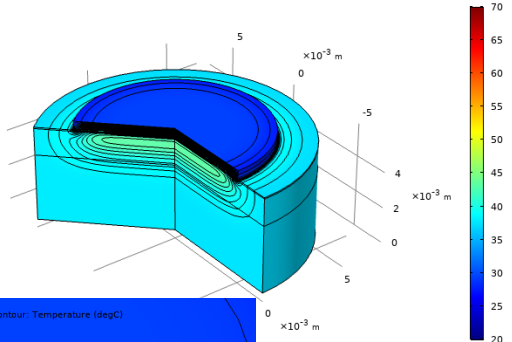
Time=0.1 s Surface: Temperature (degC) Contour: Temperature (degC)



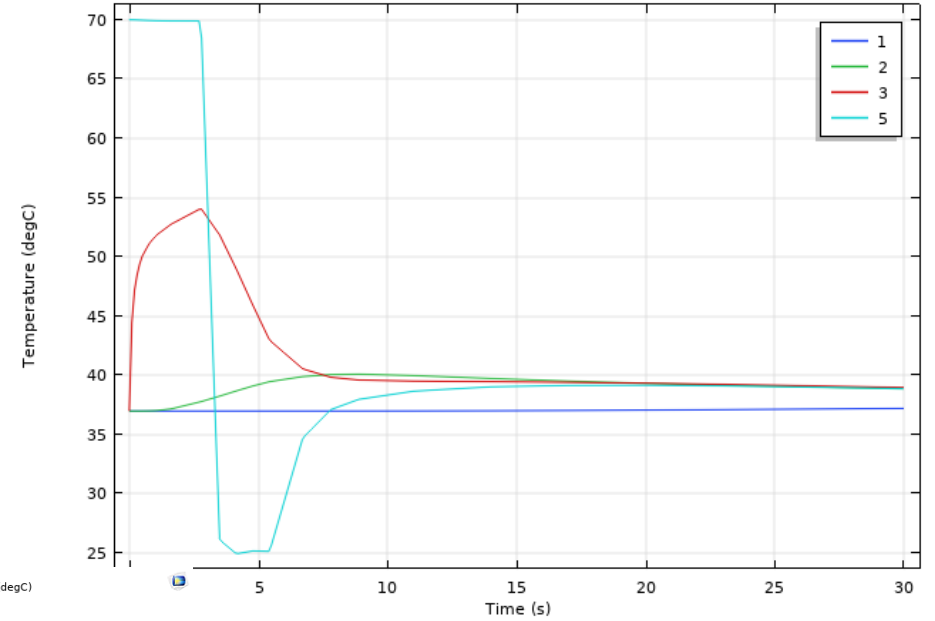
Time=2.9 s Surface: Temperature (degC) Contour: Temperature (degC)



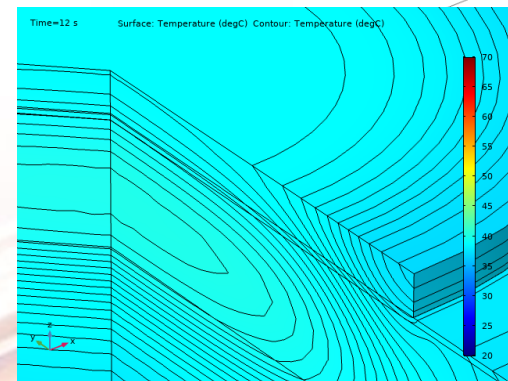
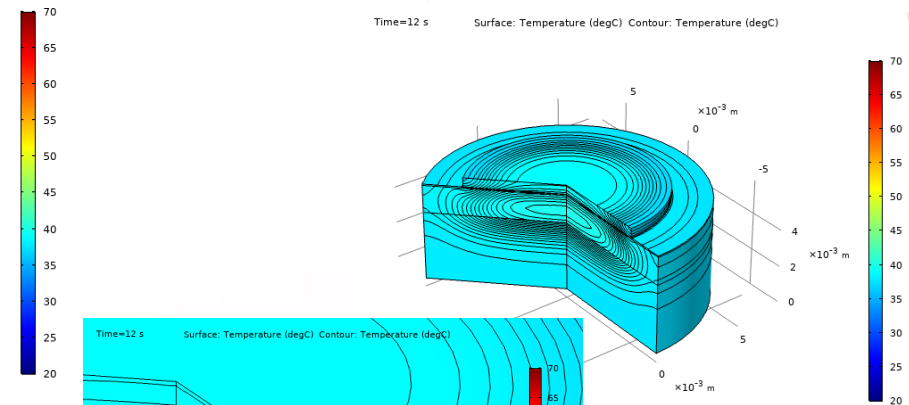
Time=6 s Surface: Temperature (degC) Contour: Temperature (degC)



Point Graph: Temperature (degC)



Time=12 s Surface: Temperature (degC) Contour: Temperature (degC)



מודל תרמי של טיפול בכוויה

Heat
conduction

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{\text{ted}}$$
$$\mathbf{q} = -k \nabla T$$

$$-\mathbf{n} \cdot \mathbf{q} = q_0$$
$$q_0 = h(T_{\text{ext}} - T)$$

Heat
convection

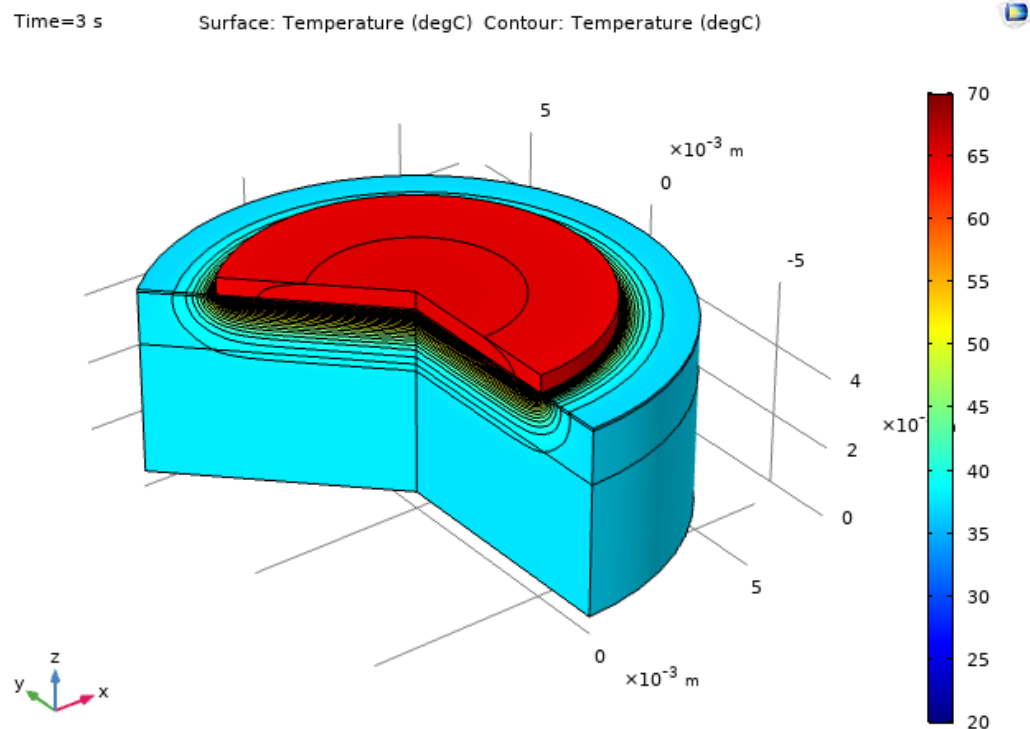
Phase change
material

$$\rho = \rho_{\text{solid}}$$
$$C_p = \theta_1 C_{p,1} + \theta_2 C_{p,2} + L_{1 \rightarrow 2} \frac{\partial \alpha_m}{\partial T}$$
$$\alpha_m = \frac{1}{2} \frac{\theta_2 - \theta_1}{\theta_1 + \theta_2}$$
$$k = \theta_1 k_1 + \theta_2 k_2$$
$$\theta_1 + \theta_2 = 1$$

Biological
tissue

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{\text{bio}}$$
$$Q_{\text{bio}} = \rho_b C_{p,b} \omega_b (T_b - T) + Q_{\text{met}}$$

אימות המודל



- תוצאות הסימולציה לאחר 3 שניות של חשיפה לגוף החם מוצגת באיור הבא
- חושבה הטמפרטורה בעומק הדרמיס לאחר 3 שניות כאשר: $x=1.575\text{mm}$, $t=3\text{sec}$

– תוצאת החישוב האנליטי שהתקבל: $T(x,t) = 38.19^\circ\text{C}$

– תוצאת החישוב בקומסול: $T(x,t) = 38.27^\circ\text{C}$

- חושב עומק חדירת גל החום (המיקום שבו הטמפ' השתנתה בכ-1%, לאחר 3 שניות.

– מתוך הפתרון האנליטי מתקבל כי $\delta = 1.906\text{mm}$

– תוצאת הסימולציה בקומסול: $\delta = 1.894\text{mm}$

- התוצאות מצביעות על התאמה מצוינת בין המודל בקומסול לבין המודל האנליטי.

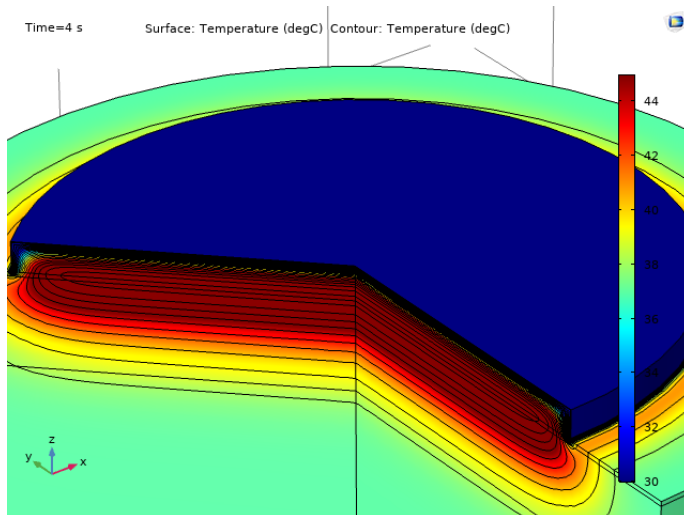
אנרגיה ליחידת שטח העוברת לעור

- על מנת לחשב את כמות האנרגיה ליחידת שטח העוברת לעור במהלך 3 שניות, יש לבצע סכום אינטגרלי של הספק החום ליחידת שטח בכל צעד זמן.
- $\int_0^{3sec} (\text{heat flux to skin}) dt = \sum E$
- לצורך כך, יש להוסיף למודל את המשוואה הבאה:
- $\text{heat flux to skin} = \frac{d(\sum E)}{dt}$
- מחישוב זה עולה כי האנרגיה ליחידת שטח העוברת את העור במהלך 3 שניות הינה:
- $\frac{\sum E}{A} = 76,000 \frac{J}{m^2} = 1.816 \frac{cal}{cm^2}$
- קיים מידע לגבי דרגת הכווייה כתלות בכמות האנרגיה ליחידת שטח העוברת אל העור.

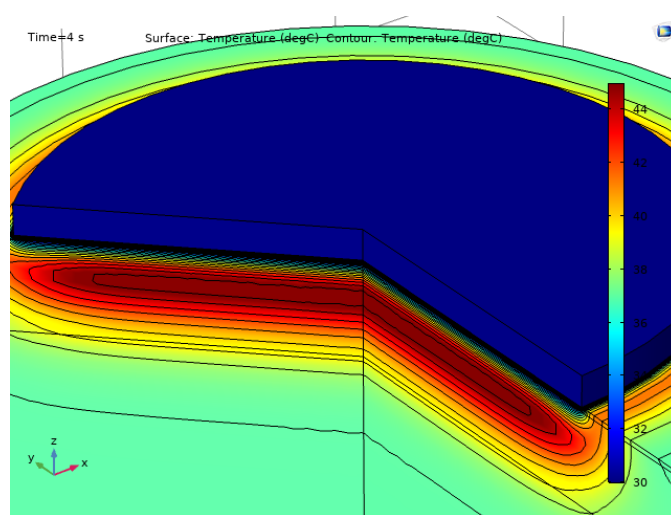
Between epidermis and dermis

- After 4 sec.

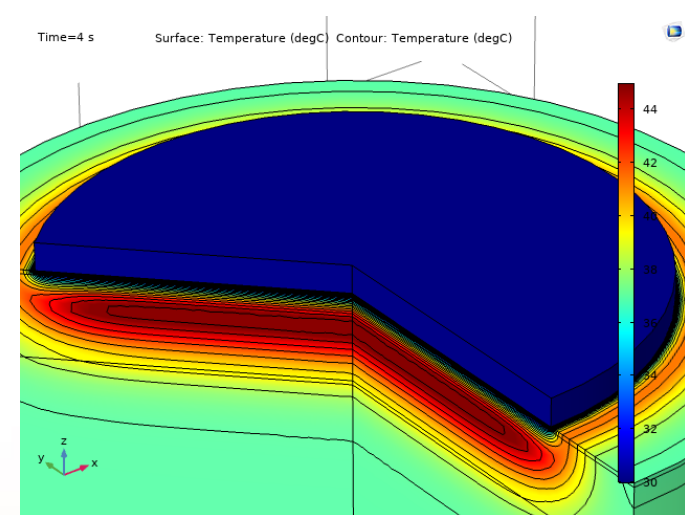
Silverol



Dermafence F20



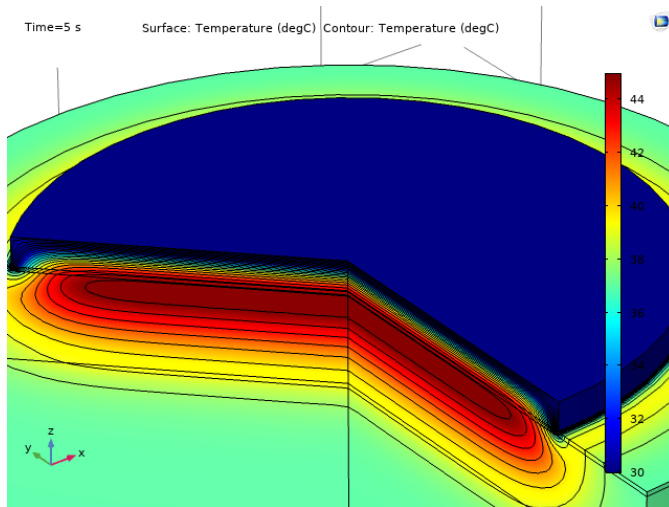
Dermafence F44



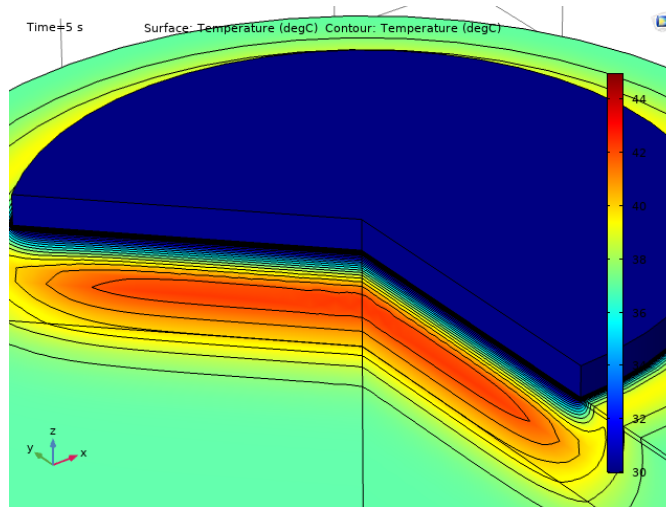
Between epidermis and dermis

- After 5 sec.

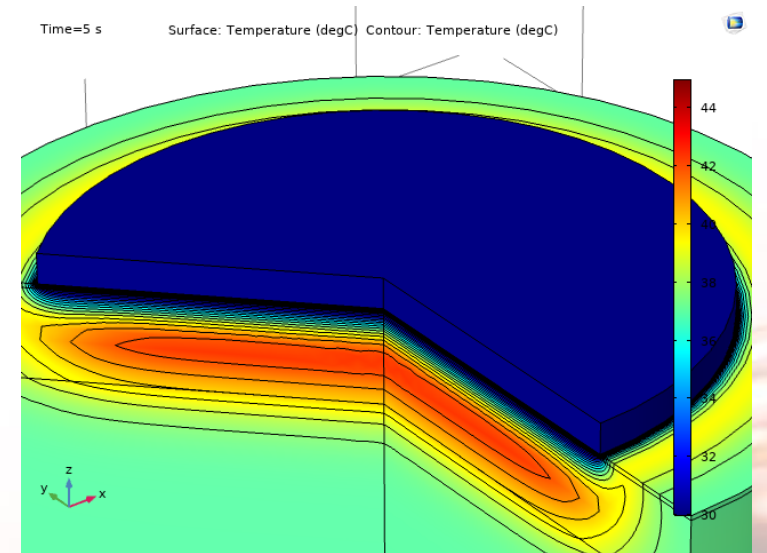
Silverol



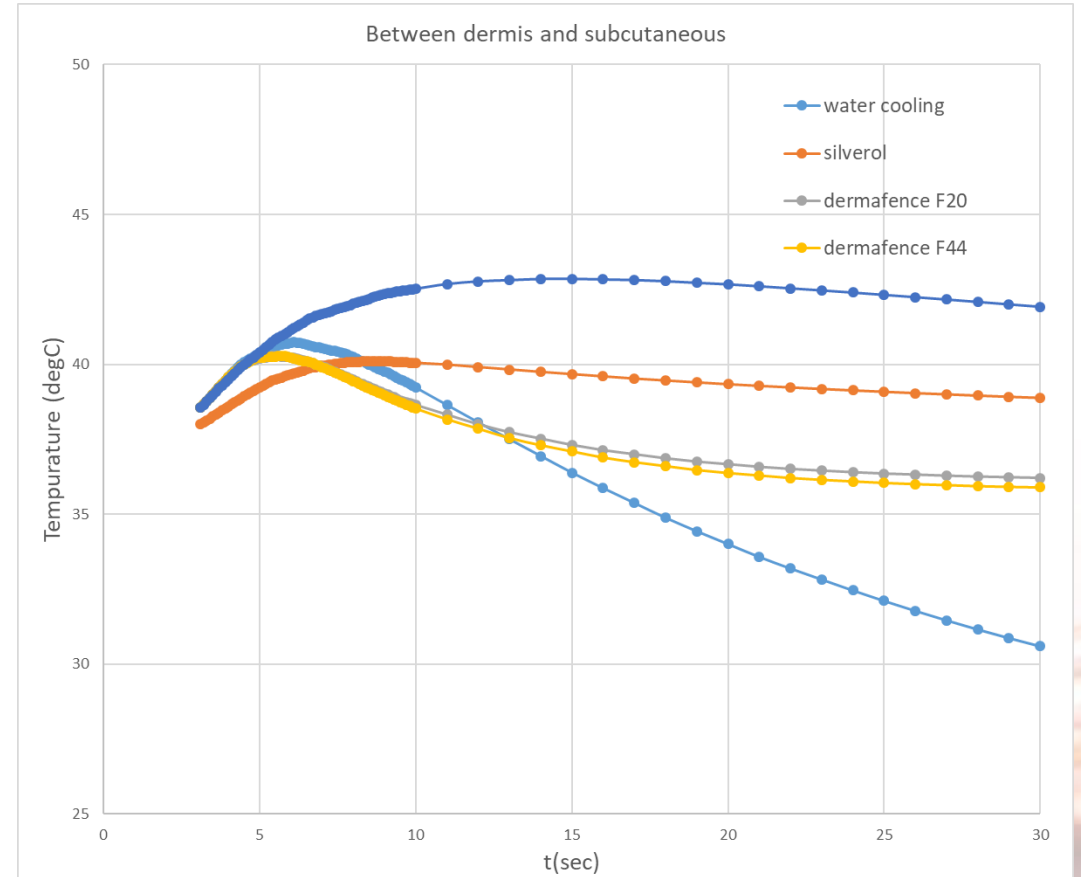
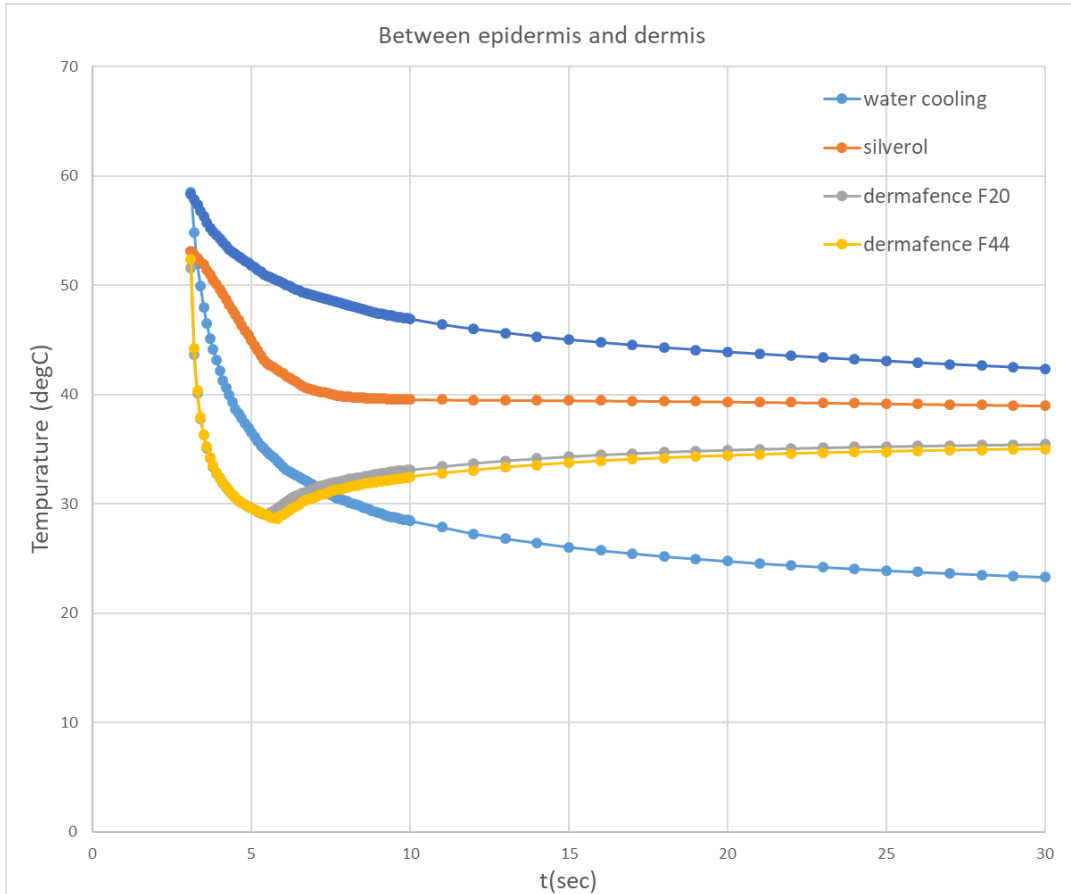
Dermafence F20



Dermafence F44



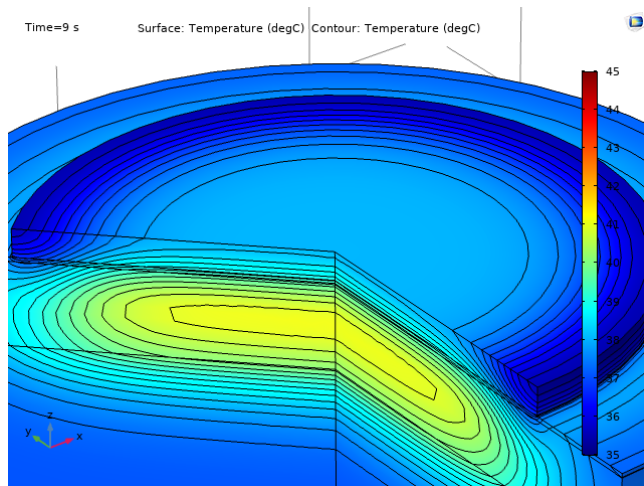
Point temperature vs. time



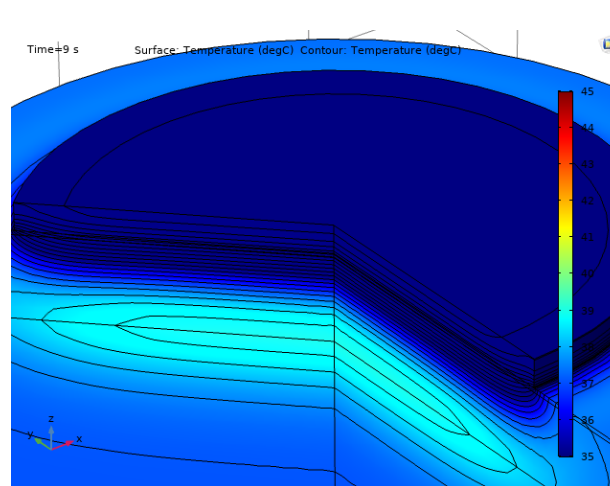
Between dermis and subcutaneous

- After 9 sec.

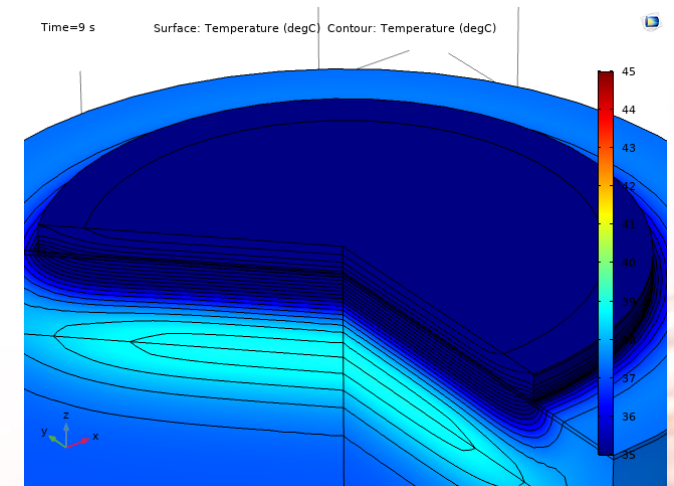
Silverol



Dermafence F20



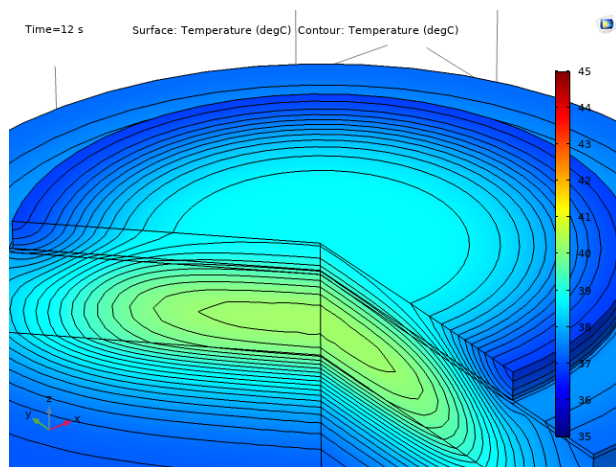
Dermafence F44



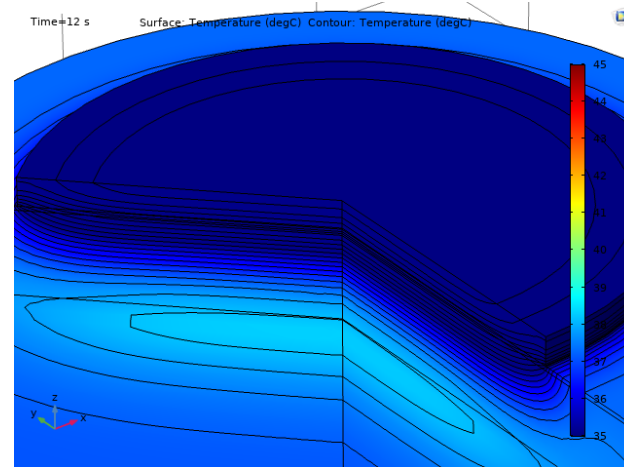
Between dermis and subcutaneous

- After 12 sec.

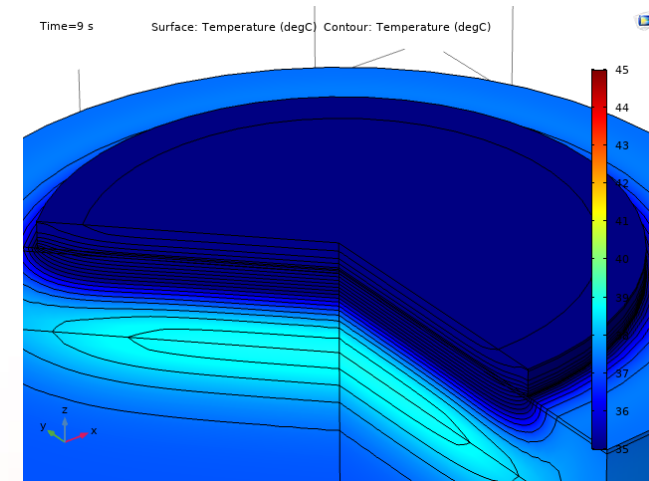
Silverol



Dermafence F20



Dermafence F44



Device for *Un*-blocking and *Removing* Secretions from Airways (DURSA)

Team:

Soroka+BGU

Dr. (MD) Yuval Cavari

Prof. David Katoshevski

CCHM+ U. of C

Dr. (MD) Iris Little

Prof. Effie Gutmark

We combine fluid dynamics with acoustics and use the combined waves in order to un-block/release the airways from mucus/secretion



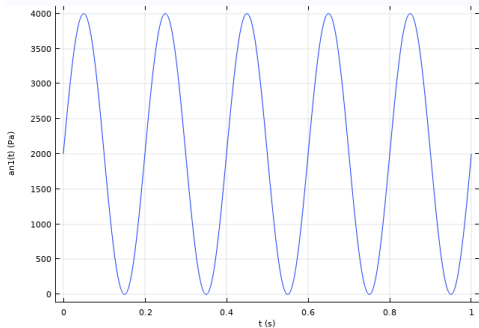
Flow + Acoustics + Non-Newtonian Material

מודל לניתוח זרימה בקנה הנשימה

$$\rho(\mathbf{u} \cdot \nabla)\mathbf{u} = \nabla \cdot [-p\mathbf{I} + \mathbf{K}] + \mathbf{F}$$

$$\rho \nabla \cdot (\mathbf{u}) = 0$$

$$\mathbf{K} = \mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T)$$

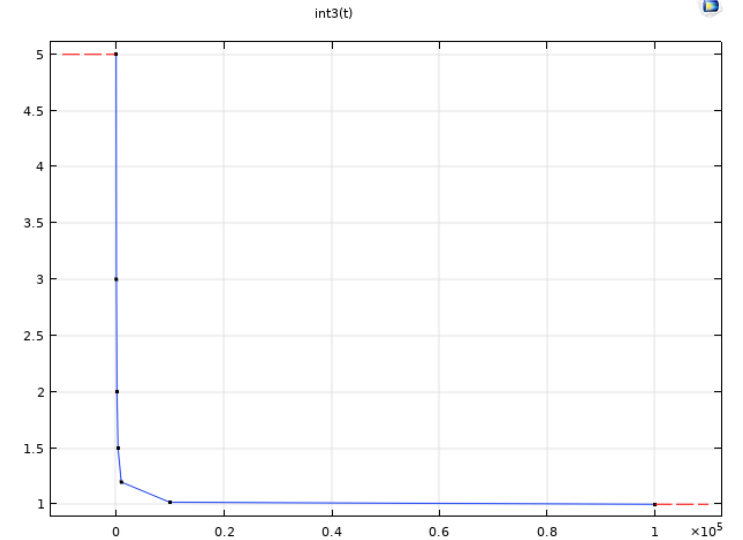


זרימה פועמת

זרימה לא
ניוטונית

מודל זרימה דו
פאזית

Pressure
acoustics



$$\frac{1}{\rho c^2} \frac{\partial^2 p_t}{\partial t^2} + \nabla \cdot \left(-\frac{1}{\rho} (\nabla p_t - \mathbf{q}_d) \right) = Q_m$$

$$p_t = p_2 + p_b$$

$$\frac{\partial \phi}{\partial t} + \mathbf{u} \cdot \nabla \phi = \gamma \nabla \cdot \left(\epsilon_{1s} \nabla \phi - \phi(1 - \phi) \frac{\nabla \phi}{|\nabla \phi|} \right), \quad \phi = \text{phils}$$

סיכום

- סימולציות נומריות הינן בעלות פוטנציאל לסיוע רב בתחומים רבים, גם כאלה שנחשבים פחות "קלאסיים" כגון במקרים שפגשנו בהרצאה זו.
- באפליקציות רפואיות רבות ניתן להעזר בסימולציות בתחומים כגון מעבר חום, זרימה, חוזק מכני ועוד.
- תהליכים ביולוגיים משלבים תופעות מעבר, ותופעות פיזיקליות רבות, ולכן כאשר מבצעים אנליזה של תופעה המתרחשת בגוף האדם, לרוב האנליזה לא כוללת את כל התופעות המתרחשות בעת ובעונה אחת.
- בכל זאת ניתן ללמוד מן האנליזות על השפעתן של תופעות המעבר על התהליך כולו, ובכך לתרום לתהליך המחקר והפיתוח.

תודה רבה