HUMAN COMMON WART REMOVAL: A FEM MODEL FOR CRYOSURGERY PROCEDURE

Sebastian Cornel FAUR[1], Alexandru M. MOREGA[2]

Negul uman comun face parte din categoria infecțiilor cauzate de un virus din familia papilloma virus (HPV). Aceste formațiuni tumorale benigne pot fi înlăturate prin diverse metode medicale precum chirurgie clasică, cauterizare electrică, criochirurgie, sau cauterizare laser. Lucrarea prezintă un model şi rezultate de simulare numerică a procedurii de extirpare criogenică a negului comun. Obiectivul propus este alegerea agentului de răcire optim pentru minizarea timpului de extirpare şi prevenirea reapariției negului. Procedura propusă, în 2 etape, urmăreşte şi minimizarea efectelor termice distructive asupra țesutului înconjurator, sănătos.

Common wart is a type of infection caused by a virus from the human papilloma virus (HPV) family. These benign tumors can be removed by medical procedures like classic surgery methods, electrical cauterization, cryosurgery, and laser surgery. This paper presents a model and numerical simulation results for cryogenic removal 2-phases procedure of human common wart. The paper's purpose is the selection of an optimal cooling agent, to minimize the removal time and prevent wart regrowth. Therewith, the 2-phases procedure follows to minimize the destructive thermal effects on surrounding healthy tissue.

Keywords: warts, liquid nitrogen, cryosurgery, heat transfer, bioheat equation, numerical simulation, FEM

1. Introduction

The wart (*verruca vulgaris*) represents a type of infection caused by viruses in the *human papilloma virus* (HPV) family. There are more than 60 types of HPV viruses. HPV is one of the most common infections in the world infecting approximately 40% of all humans. Some people are naturally more resistant to HPV viruses, and don't seem to get warts as easily as other people.

Warts come in many sizes, colors, and shapes. They can appear anywhere on the body. Each type prefers a certain part of the body. For example, some types of HPV produce warts on the skin, others cause warts inside the mouth, and still others produce warts on the genital and rectal areas. Viruses enter the body

[1]PhD. Student, Laboratory for Electrical Engineering in Medicine, Faculty of Electrical Engineering, University POLITEHNICA of Bucharest, Romania
[2] Professor, Faculty of Electrical Engineering, University POLITEHNICA of Bucharest, Romania, amm@iem.pub.ro

through skin or mucous membrane. They usually do not produce symptoms for one to eight months after entering the body. Warts emerge skin-colored, rough to the touch, but they can also be dark, flat, and smooth.

The most common types of warts include common hand warts, foot (plantar) warts, flat warts, or genital warts. *Common hand warts* grow around the nails, on the fingers, and on the backs of hands. They appear most often in the regions where the skin is broken. *Foot warts* are also called plantar warts. Plantar warts usually occur on the ball of the foot, the heel and the bottom of the toes. The skin in these areas is subject to weight, pressure and irritation, and has a tendency to crack or break open, providing an opening for the virus. Foot warts usually do not stick up above the skin. *Flat warts* are smaller and smoother than other kinds of warts and tend to grow in large numbers. Although they can appear anywhere on the body, flat warts appear most often on the legs of women and on the faces of children and young adult males. *Genital warts* are a type of sexually transmitted disease (STD). A sexually transmitted disease is a condition that is passed from one person to another during sexual activity. The forms of HPV that cause genital warts are very contagious.

Our purpose is to develop a model aimed to allow unveiling the outlining heat transfer process that occurs during the wart removal medical procedure. To this end, we consider a simplified 2-D axial symmetric mathematical model for the numerical simulation of the extirpation by cryosurgery of a human common wart. The model is solved numerically by the finite element method.

Cryosurgery offers some advantages as compared to existing traditional methods because no anesthetic is needed and freezing causes only a minor stringing sensation [3]-[7], [9]. The procedure deals with liquid gases like oxygen, nitrogen, carbon dioxide, and hydrogen. The boiling points for these gases are: oxygen (–78.5 Celsius degrees), nitrogen (–196 Celsius degrees), carbon dioxide (–183 Celsius degrees) and hydrogen (–253 Celsius degrees) [8]. For all these cooling agents we have to prescribe the optimal time for removing the wart with both parts (the superficial part (wart head) and the embedded part (wart root). Adiabatic bandages are used to prevent the destructive thermal effects on surrounding skin.

2. Mathematical and numerical model

The mathematical model that governs the heat transfer process is based on bio-heat equation, described by equation (cylindrical coordinates) [1]

$$\rho c_p \frac{\partial T}{\partial t} = k\left[\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{\partial T}{\partial r}\right) + \frac{\partial^2 T}{\partial z^2}\right] + \rho_b c_b v_b \rho_{skin}\left(T_a - T\right), \tag{1}$$

where k is thermal conductivity of tissue, ρ_b, c_b, ν_b are blood parameters and represent density, specific heat and cinematic viscosity, ρ is either ρ_w or ρ_{skin} respectively the either the wart or the skin density (depending on the region where eq. (1) is utilized), T is the temperature, and T_a is the basal (metabolic) temperature. The values for these parameters are [2]: $\rho_b = 1060\ kg/m^3$; $c_b = 3890\ J/kg\cdot K$; $\nu_b = 2.5\cdot 10^{-6}\ m^2/s$; $\rho_w = \rho_{skin} = 1500\ kg/m^3$; T_a = 273.15+ +37 = 310.15 K, r and z are the coordinates (cylindrical). The temperature dependence of the specific heat and thermal conductivity are here approximated by the analytical expressions

$$c_p(T) = [-\mathrm{erf}(x+3.2) + \mathrm{erf}(x+3.4)]\cdot 799800/2 + 0.3\ [J/kg\cdot K], \tag{2}$$

$$k = [\mathrm{erf}(x+1)\cdot 0.2] + 0.4\ [W/m\cdot K] \tag{3}$$

that fit experimental data [2]. Here erf(x) is the *error function* [10], defined by twice the integral of the Gaussian distribution with 0 mean ½ variance

$$\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}\,\mathrm{dt}. \tag{4}$$

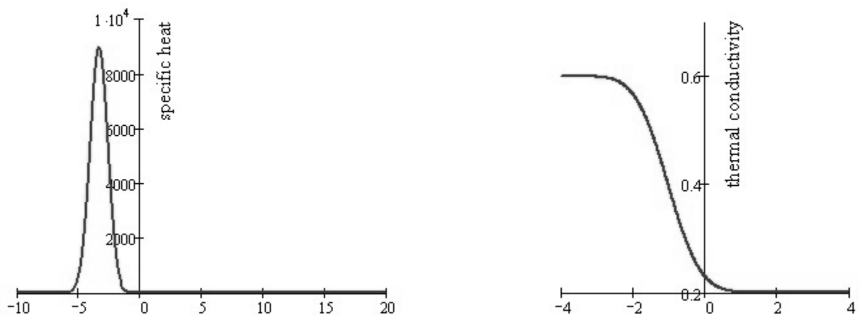

Fig.1. Temperature dependence for specific heat and thermal conductivity.

The temperature dependence of the specific heat and thermal conductivity may be dealt with by other techniques, for instance the enthalpy approach reported by [11]. The proposed model is based on the following assumptions:

- the model is 2-D, axial-symmetric;
- wart's shape is an ellipse (semicircle for the wart head, and semi ellipse for the wart root);
- the biological tissue limit is -20 Celsius degrees; under this temperature

the tissue is irreversible damaged;
- the size of the computational domain (the basal tissue) was set such that, from heat transfer point of view, it is at thermal equilibrium with the neighboring tissue, out of which it is “carved”;
- the wart root is embedded only superficially in the healthy tissue, and the nerves in that region may not be affected by cryosurgery.

The physical domain is presented in Fig.2, and the computational in Fig 3.

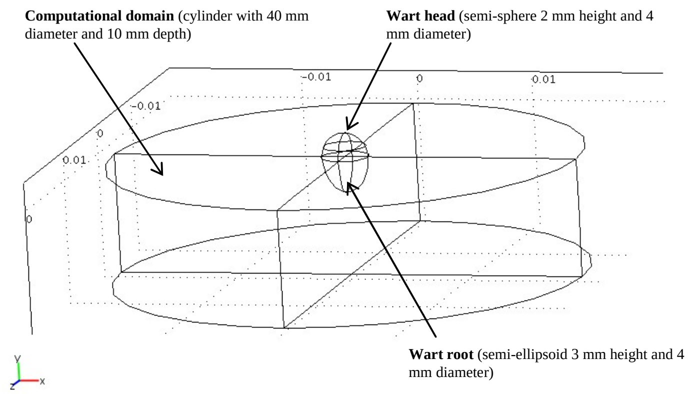

Fig.2. Physical domain for wart removal procedure (3-D view) – dimensions are in meters.

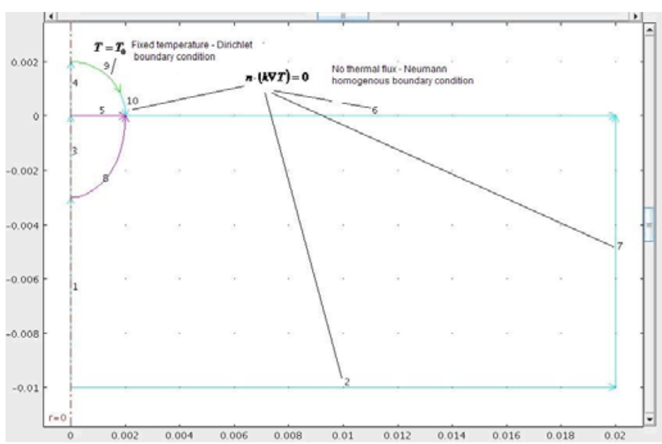

Fig.3. Computational domain and the boundary conditions (BCs).

As noticeable, the wart is modeled by an ellipse of 2 and 3 millimeters radii; the computational domain is 4 cm long (*r*-axis), and 1 cm deep (*z*-axis). The boundary conditions are as follows: thermal insulation (adiabatic) for segments 1-

8, fixed temperature (Dirichlet condition) for segment 9. The thermal insulation boundary condition on segment 10 appears only when an adiabatic bandage around the wart is present (in order to protect surrounding skin).

The system under investigation is assumed at thermodynamic equilibrium, itself and with the surrounding tissue; this means that its temperature is uniform *i.e.*, the normal human body temperature (310.15 *K*). A transient analysis was performed in the investigated model. The initial temperature is the normal human body temperature (310.15 *K*) and the valid time for this approach is given with the respect of a Neumann homogenous boundary condition on the external boundary of computational domain, which means negligible small heat transfer outside the computational domain. This condition conducts to a physical validity (*i.e.*, the sampled tissue is at thermal equilibrium with the surrounding tissue).

The associated numerical model is based on finite element method (FEM) in Galerkin formulation as implemented in COMSOL [1]. Figure 4 presents an example of domain's FEM mesh used in order to solve for the model.

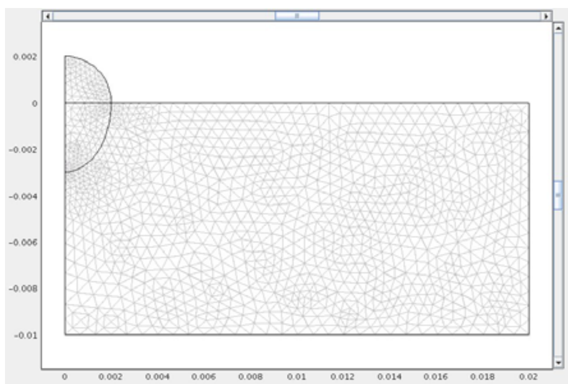

Fig.4. FEM unstructured mesh made of 2,552 triangular, Lagrange, elements.

The algebraic system of equations is solved by a direct solver (UMFPACK, [1]).

3. Results and discussion

First, it is necessary to choose the proper liquid gas. The monitored parameter is the removal time, in order to destroy the benign tumor cells. Initially no adiabatic bandage is used. Simulation was conducted for 30, 60, 90 and 120 s of applying the cooling agent on the wart head surface. The 253 *K* isotherm lines are shown in the following figures. The tissue above this limit (temperatures lower than 253 *K*) is irreversible affected, *i.e.*, the tumor cells are destroyed. Apparently, 30 seconds are enough time to remove superficial wart, but without removal of the root the wart can easily reappear.

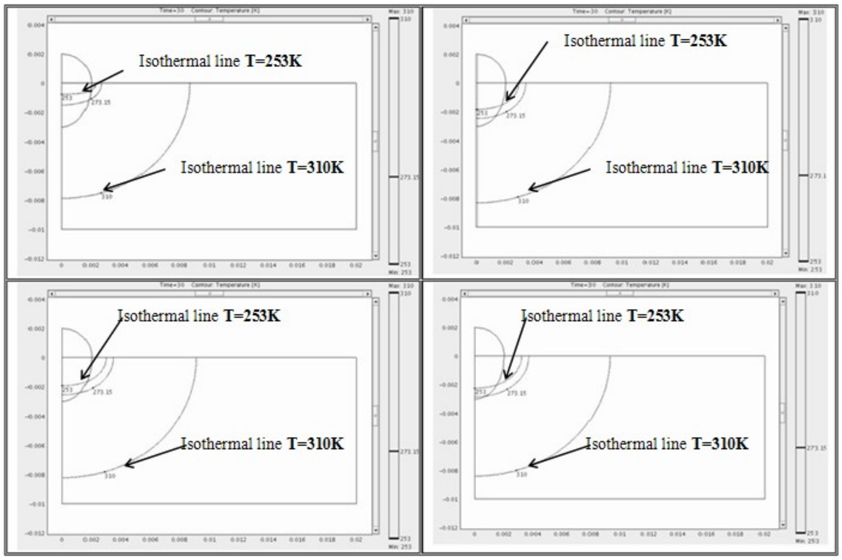

Fig.5. Wart temperature after 30 s (oxygen – up left, carbon dioxide – up right, nitrogen – down left, hydrogen – down right); isothermal lines for 253 *K* (lower limit for living human body tissue), 273.15 *K* and 310 *K* (normal human body temperature).

Figures 6, 7 show that neither 60 nor 90 seconds of direct exposure to cooling agents are enough to completely remove the wart.

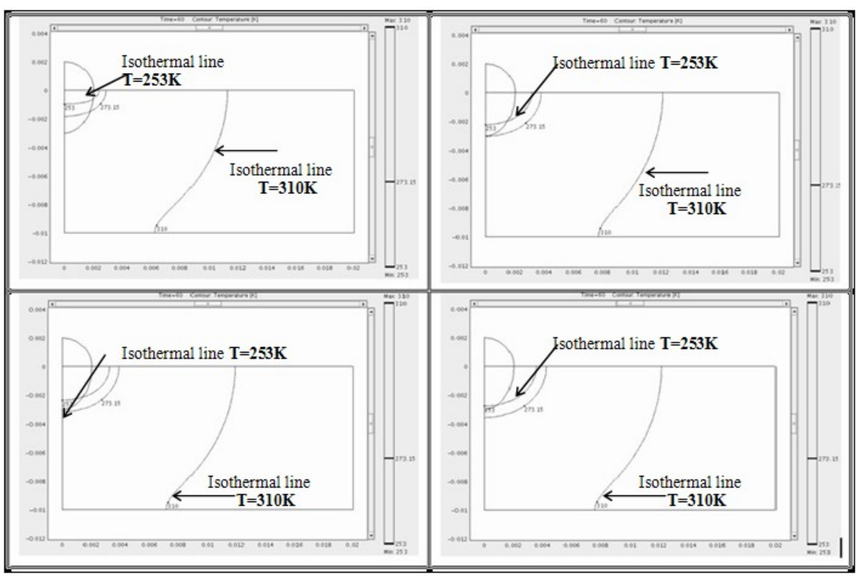

Fig.6. Wart temperature after 60 s (oxygen – up left, carbon dioxide – up right, nitrogen – down left, hydrogen – down right); isothermal lines for 253 *K* (lower limit for living human body tissue), 273.15 *K* and 310 *K* (normal human body temperature).

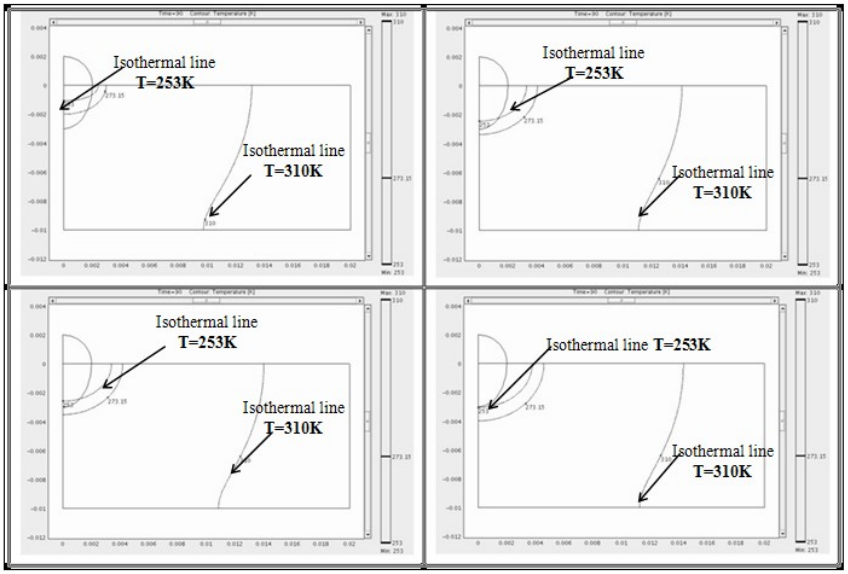

Fig.7. Wart temperature after 90 s (oxygen – up left, carbon dioxide – up right, nitrogen – down left, hydrogen – down right); isothermal lines for 253 *K* (lower limit for living human body tissue), 273.15 *K* and 310 *K* (normal human body temperature).

When either liquid nitrogen or liquid hydrogen is utilized, the wart is totally removed in 120 s.

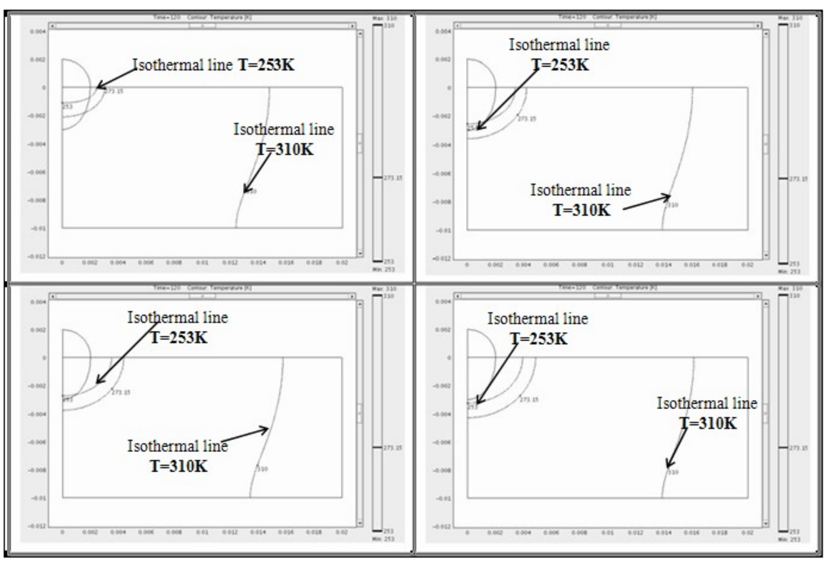

Fig.8. Wart temperature after 120 s (oxygen – up left, carbon dioxide – up right, nitrogen – down left, hydrogen – down right); isothermal lines for 253 *K* (lower limit for living human body tissue), 273.15 *K* and 310 *K* (normal human body temperature).

Still, this is not a satisfactory result because the removal time is too long and the computational domain becomes too small in order to preserve the imposed zero-flux (homogeneous Neumann condition) on the boundaries: one can observe the maximum temperature is about 310.14 *K*, a rather small variation but enough to jeopardize the results. Extending the computational domain is questionable, and will conduct to unpractical results. As a first conclusion, hydrogen and nitrogen are the best choices but a solution to remove the wart with respect of practical principles is still needed.

In practice is not so easy to handle with liquid hydrogen. This gas will gradually leak away (typically 1% per day) [8] and requires complex storage technology, more severe than liquid nitrogen. This is the reason that from now on our attention will be focused on procedure with liquid nitrogen. So, *we propose a 2 phases procedure for cryogenic wart extirpation*, explained as follows.

In phase 1 only the wart's head is removed. After freezing a blister can occur, and in one up to six days and the wart and surrounding dead skin fall off by themselves. In phase 2, the embedded root is to be destroyed.

Phase 1. The wart surface is totally exposed, no adiabatic bandage present. One can observe (Fig. 9) that after 4.2 s the wart's head is irreversible affected but, unfortunately, the surrounding healthy tissue is affected too (about 0.5 mm).

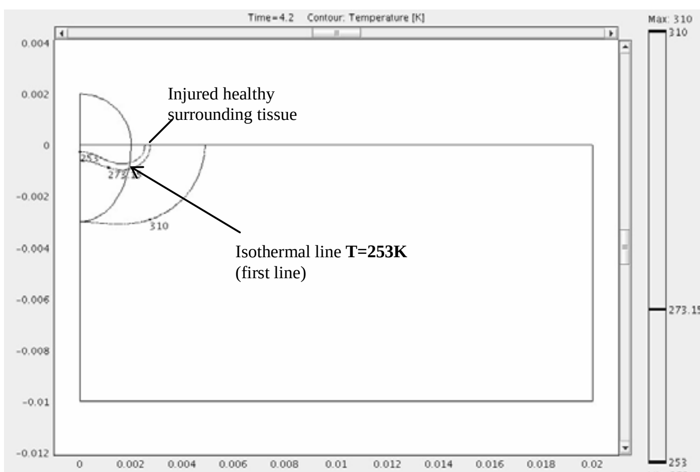

Fig.9. The wart temperature diagram after 4.2 s of exposure (no adiabatic bandage).

In this case an adiabatic bandage is mandatory. But how is designed this bandage in our model? We draw a point on the circle (wart surface) under an alpha angle in so manner that the boundary is split in 2 parts (9 and 10). On the boundary segment 9 we imposed temperature (Dirichlet condition), and on boundary segment 10 (corresponding to the bandage) we set thermal insulation condition. The exposure time increases from 4.2 to 5.6 s, but the collateral unpleasant effects are minimized.

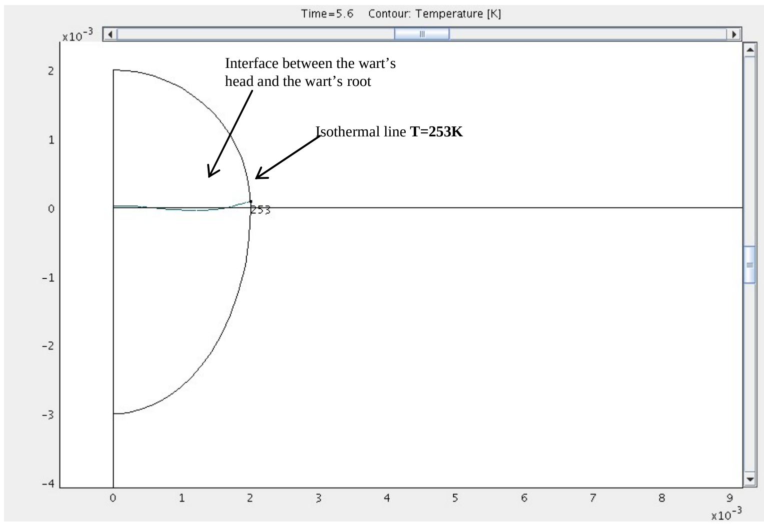

Fig.10. The wart temperature diagram after 5.6 s of exposure, with a 0.85 mm adiabatic bandage (corresponding to a $(\pi/6.9)$ angle).

Phase 2: Removal of wart's root. After the blister falls off by itself we continue with the second phase of procedure. The first choice would be to apply liquid nitrogen on the entire remaining wart surface like, as presented in Fig. 11.

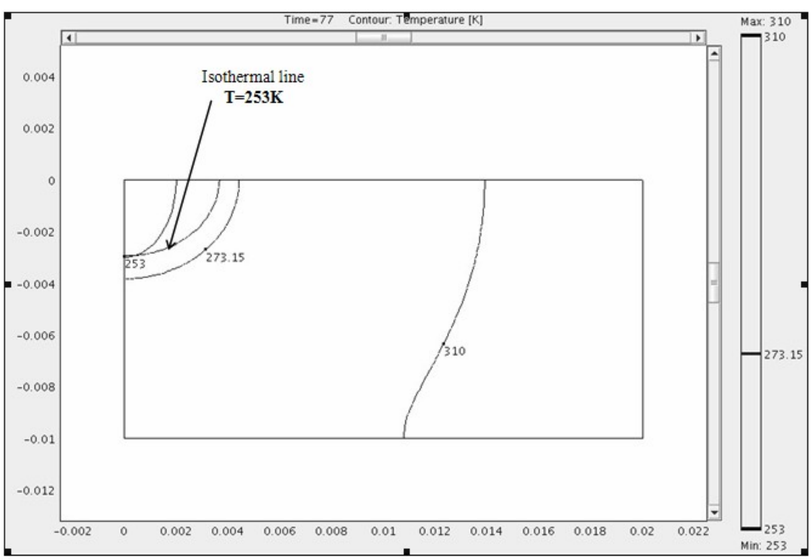

Fig.11. The removal of wart root (76 s necessary time).

The necessary time for removing the entire wart root is then about 76 s, but again, unfortunately, the surrounding healthy tissue would be destroyed. Compared to the first phase, the presence of the adiabatic bandage is useless. Reducing the exposed surface with bandage will result in increasing the exposure time and all these will finally conduct to a fictitious model with no practical results. So, the alternative proposal to direct exposure is insertion of a probe (needle) filled with liquid nitrogen inside the wart root, as in shown Fig. 12.

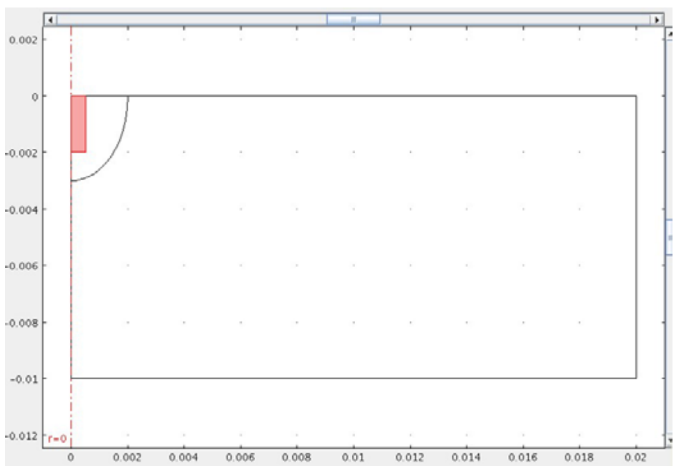

Fig.12. A cryoprobe (1 mm diameter, and 2 mm depth), filled with liquid nitrogen, is inserted within the wart root.

Fixed temperature conditions on probe's boundaries will conduct to expected results after 19 s only with the respect of computational domain. That means that after 19 s the entire wart's root is damaged and the outside computational domain temperature is the same with the initial system temperature, *i.e.* 310 *K* (normal human body temperature).

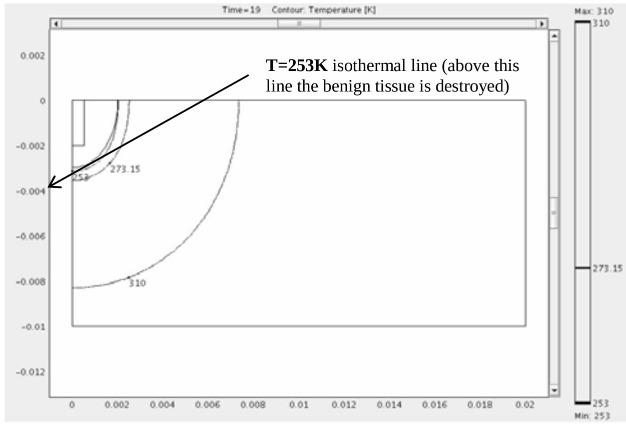

Fig.13. Phase 2 – Wart root removal after 19 s.

4. Conclusions

The paper presents a 2 phases procedure for removal of a human common wart as an alternative to classical procedure in one single phase. The goal in the first phase is the removal of the wart head, and this goal is accomplished after a direct exposure to a cooling agent. In order to prevent healthy surrounding tissue to be affected an adiabatic bandage is needed. After this phase a blister can occur. After the blister falls off by itself we can proceed with the second phase of procedure: the wart root elimination. Our model proposes two options to obtain this. The first option is direct exposure to cooling agent and the second option is the introduction of a cryoprobe, filled with cooling agent, inside the wart root. The second option leads to a shorter removal time compared with direct exposure.

The proposed procedure brings several benefits: the affected surrounding healthy tissue is minimized and the reduced removal time relative to the classical procedure of total wart exposure in one single phase.

Acknowledgements

The work was conducted in the Laboratory for Electrical Engineering in Medicine at the Faculty of Electrical Engineering.

R E F E R E N C E S:

[1] COMSOL Multiphysics, v. 3.4, Heat Transfer Module, Comsol A.B., 2008.
[2] *K. Cuneo, J. LeBarron, J. Reynolds, C. Tiberio, S. Yoo*, Cryogenic treatment of the Common Wart, Cornell University Electronic Library, “eCommons@Cornell”, Nov. 2004.
[3] *D.A. Mark*, Cryosurgery for Common Skin Conditions, American Family Physician, **69**, 10, 2365-2372, 2004.
[4] *J.P. Homasson*, Cryosurgery: state of the art and perspectives in 2001, Bulletin of IIR No.

2001-4.
[5] *M.C. Luba, S.A. Bangs, A.M. Mohler, D.L. Stulberg,* Common benign skin tumors, Amer. Fam. Physician, **67**, 729-738, 2003.
[6] *R.R. Lubritz*, Cryosurgical approach to benign and precancerous tumors of the skin, S.A. Zacarian ed. Cryosurgery for skin cancer and cutaneous disorders, St. Louis, Mosby, 283-297, 1985.
[7] *C. Cooper*, Cryotherapy in general practice, Practitioner, **245**, 6, 954-956, 2001.
[8] Hydrogen Safety – article from Wikipedia; http://en.wikipedia.org/wiki/Hydrogen_safety
[9] *M.D. Andrews*, Cryosurgery for Common Skin Conditions, American Family Physician, **69**, 10, May 15, 2004.
[10] *C.I. Mocanu*, The theory of the electromagnetic field, Ed.Did.Ped., Bucharest, 1981.
[11] *C. Flueraşu, C. Flueraşu*, Calcul des régimes transitoires thermiques dans les matériaux avec propriétés dépendantes de la température, Rev. Roumaine Sci. Techn. Électrotech. et Énerg., **53**, 3, 269-278, 2008.