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Computational Study of Thermal Wave Propagation in Human Skin During Plasmolysis of Water

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Abstract: In carrying out the plasma electrolysis of water like experiments, lot of heat is emitted. This heat has a serious life hazards. A numerical studied has been carried out to investigate the Acute paronychia infection and other heat injuries, during plasma electrolysis of water experiments. The parametric dependence of the infection as a function of conductive, convective and radiative heat fluxes, irradiation time and heat diffusion through nail bed (epidermis) were focused with respect to different parameters of the plasma electrolysis of water. The effect of catalysts was also taken into account.

Keywords: Acute Paronychia, Plasma electrolysis, Heat flux, diffusion, Electrolytes.

I. INTRODUCTION

In humans, finger-nails and toe-nails perform the physiologic functions of protecting the distal phalanges, increasing mechanical toehold, and enhancing fine touch. We also use them for common functions such as scratching, grooming, and aesthetic adornments. Nail distortions may result from a number of etiologies, and surgical modalities may be needed to diagnose and treat a number of abnormalities.

Nail deformities that require nail elimination can secondary occur to anything that causes injury or bend of the nail bed. This may comprise infections self-mutilation, tumor, or trauma [1, 2]. Both acute and chronic infections start with a rupture in the epidermis. An acute infection is associated with trauma to the skin such as a hang-nail, ingrown- nail, or nail-biting [3].

Paronychia is one of the most common infectivity of the hand. Paronychias are localized, superficial infections or swellings of the perionychium (epidermis bordering the nails). Paronychial infections develop when a commotion occurs between the seal of the proximal nail fold and the nail plate that lets a portal of entry for assaulting organisms.

Non-infectious causes of paronychia include thermal contact irritants and undue wetness. Clinically, paronychia presents as an acute or chronic condition. People with occupations such as industrial worker ,baker, bartender and dishwasher seem predisposed to developing chronic paronychia[4].

The most widespread bacteria responsible are Staphylococcus aureus. Other bacteria that are less normally involved are Streptococcus class and Pseudomonas species. A chronic infection is associated with repeated irritation such as exposure to heat, detergents and water (Figure1). Most chronic infections are originated by Candida albicans or other fungi [5].

In plasma electrolysis experiments, a lot of acids and basis are used as a catalyst [6-9]. The different electrolytes such as NaCl, NaOH, KOH, K_2CO_3, Na_2CO_3 and H_2SO_4. were used by the researchers [12-21]. During electrolysis access heat was reported [22]. IR and heat exposure each induces cutaneous angiogenesis and inflammatory cellular infiltration, disrupts the dermal extra cellular matrix by inducing matrix metalloproteinases, and alters dermal structural proteins, thereby adding to premature skin aging [23-25]. A photo-biological impact of ultraviolet (UV) radiation on the epidermis was already reported [26].

Present work on the paronychia infection during plasma electrolysis of water has make known the important parameters which played a vital role in the enhancement of said infection.

The role of heat fluxes (conduction, convection and radiation) have been investigated numerically. Apart from this, heat diffusion through nail bed has been studied carefully. The effect of catalysts was also described observantly.

II. THEORY

A. *Plasma electrolysis of water:*

Plasma electrolysis of water like experiments contain a fuel cell containing electrodes connected with a DC power supply and water mixed with some electrolyte(acid or base).The chemical reaction takes place I fuel cell is

Cathode (reduction): $2\,H_2O + 2e^- \rightarrow H_2 + 2\,OH^-$ --- (1)

Anode (oxidation): $4\,OH^- \rightarrow O_2 + 2\,H_2O + 4\,e$ ----(2)

Overall reaction: $2\,H_2O \rightarrow 2\,H_2 + O_2$ ---- (3)

The total bonds formed are

Two H-H bonds.

One O=O bond

Four O-H bonds are formed

The total heat energy release during the reaction

$$\Delta H = 2(H-H) + (O=O) - 4(O-H)$$

$$\Delta H = 2(436) + 499 - 4(463)$$

$$\Delta H = -481KJ$$

B. *Heat transfer by Conduction Current*

Conduction is the most major means of heat transfer when objects in thermal contact. On a microscopic scale, heat conduction crop- ups as hot, hastily moving or vibrating atoms and molecules intermingle with neighboring atoms and molecules, transferring some of their energy (heat) to these neighboring particles. In other words, heat is transferred by conduction, when neighboring atoms vibrate beside one another, or as electrons move from one atom to another. The mathematical form of conduction heat current is

$$\frac{\partial q}{\partial t} = -k\oint_s \nabla T.dA \qquad \text{------------ (4)}$$

Where $\frac{\partial q}{\partial t}$ is conduction-current, dA is the area exposed to heat, k is thermal conductivity and ∇T is the temperature gradient**.**

C. *Heat transfer by Convection Current*

The liquids or gases in hot areas are rare than in cold areas, so these ascend into the cold areas. The denser cold liquid or gas drops into the hot areas. In this way**,** convection currents that transfer heat from point to point are set up. The governing equation is

$$\frac{\partial q}{\partial t} = h\oint_s \nabla T.dA \qquad \text{-------------- (5)}$$

Where $\frac{\partial q}{\partial t}$ the convection is current, dA is the area exposed to heat, h is the heat transfer coefficient and ∇T is the temperature gradient.

D. *Heat transfer by radiation Current*

Thermal radiation is the transport of heat energy through empty space by means of electromagnetic waves. All objects with a temperature above absolute zero radiate energy. No medium is necessary for radiation to occur. Thermal radiation is a direct result of the arrangements of atoms and molecules in a material. Their movement results in the emission of electromagnetic radiation, which carries energy away from the surface. At the same time, the surface is constantly bombarded by radiation from the neighboring environment, resulting in the transfer of energy to the surface. Since the amount of emitted radiation proportional to the temperature, as a result of this, transfer of energy from higher temperatures to lower temperatures results.

The equation of radiation current is

$$\frac{\partial q}{\partial t} = \varepsilon\sigma\oint_s \Delta T^4.dA \qquad \text{---------- (6)}$$

Where $\frac{\partial q}{\partial t}$ is radiative current, dA is the area exposed to heat, ε is emissivity and σ is the Stefan–Boltzmann constant.

E. *Heat diffusion equation*

when the heat is incident on the skin, a thermal wave propagates into to the skin. The diffusion of heat by thermal wave propagation through epidermis is given by the Fick, s law of heat diffusion is

$$\frac{\partial T(x,t)}{\partial t} = D\frac{\partial^2 T(x,t)}{\partial t^2} \qquad \text{---------------- (7)}$$

Where $D = \frac{k}{c_p}$ is thermal diffusivity, k Thermal conductivity and c_p is specific heat capacity.

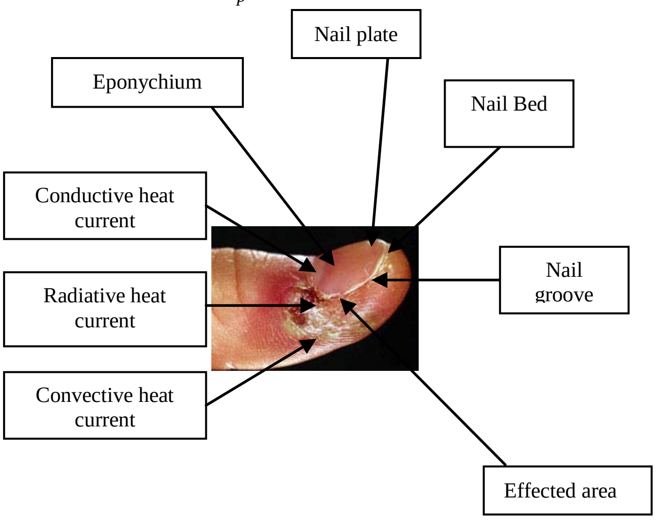

Figure 1.Image of Thumb having paronychia infection

III. RESULTS AND DISCUSSIONS

A. *Effect of Heat Currents*

Simulations study foreseen that, in order to instigate acute paronychia infection, transmission of heat currents had a significant role. These heat currents were responsible to irritate the dermal structure. Figure2 represents the affect of these heat currents as a function of time. It has been observed that these heat currents were directly amended with time. The conductive heat current was found to be more effective than the others. Conductive current leaned over the convective and radiative currents. After 50 minutes conductive heat current was at 3 Joule/sec, where as at the same time the convective heat current and radiative heat current were at 2.1 Joule/sec and 0.1 Joule/sec respectively. The reason for the more effectiveness of conductive current was that during plasma electrolysis experiments, thumb is frequently touched with fuel cell apparatus.

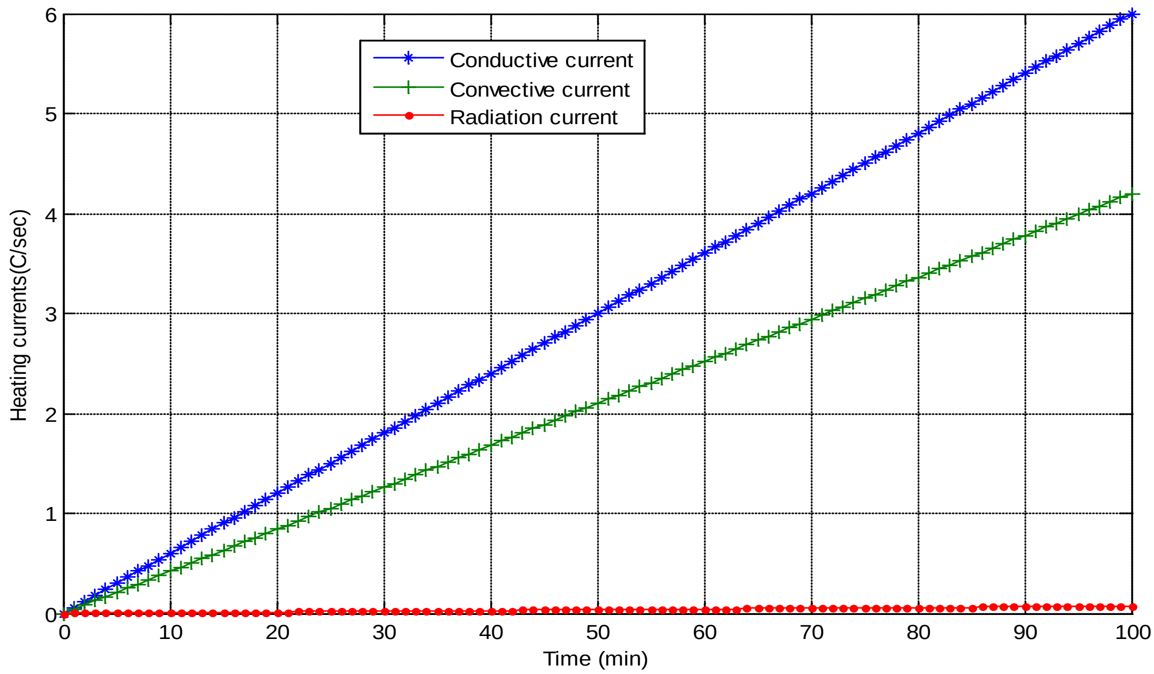

Figure 2 .A graph of heat currents transferred to skin versus time of exposure.

B. Effects of Heat flux

Figure 3 represents the affect of heat fluxes transferred to the dermis as a function of area of skin (exposed). It is examined from the simulations that heat flux changed linearly with area of skin. The conductive heat flux was found to be larger than the convective and radiative heat fluxes. At a skin area of 0.0025 m^2**,** the conductive flux was at 1600 Joule/ m^2,While at the same vicinity the convective flux was at 100 Joule/ m^2 and radiative flux was at 10 Joule/ m^2.This was again due to the hand contact (successive)with the fuel cell.

Figure 3 .A graph of heat flux transferred to skin versus area exposed.

C. Effect of heat diffusion

Another prominent factor which had a vital role to produce paronychia infection was the diffusion of heat wave in the skin dermis. In Figure 4, the diffusion temperature as a function of time is represented by graph. This graph represents that initially for shorter time interval the diffusion temperature raised rapidly while later for longer time regime temperature decreased exponentially. Initially diffusion temperatures heaved up rapidly to a peak value of $135C^o$ at a time span of 18 sec, after that it decreased exponentially and became constant, approximately after a time length of 200 sec. This was because when heat flux was focused on the skin, temperature of the skin raised but as heat wave propagated into skin, the temperature of the skin dropped. A temperature of $135C^o$ is very high for human skin. This limit of temperature will cause a serious burning effect and thermal injuries.The temperature limit for paronychia infection is $47C^o$.So after a time interval of 9 sec chances of paronychia infection would be started.

Figure 4. A graph of heat diffusion temperature versus time of diffusion

D. Effects of Catalysts

In plasma electrolysis of water like experiments, a lot of acids and bases are used as a catalyst. Acids are proton donors (H^+), and bases are defined as proton acceptors (OH^-). Both acids and bases can be active as caustics. Numerical study predicted that these catalysts caused significant epidermis damage on contact. The study divulged that when acids were used as a catalysts pH of epidermis decreased from 5.5 to 3.5.So acidity of the epidermis increased to normal value of pH 5.5. Chances of paronychia infection were increased due to chemical and thermal injuries. Similarly when bases were used as a catalysts the pH value found to be in the range of 9 to 13.5 . Alkalinity of the skin bring into being increased. This high value of alkalinity was responsible for producing thermal injuries to epidermis. These thermal injuries instigated the paronychia infection.The enhancement in acidity and alkalinity in the skin may damage the immune cells, which can cause the bacteria and fungus nourishment.

IV. CONCLUSIONS

Numerical model successfully predicted that the chances of paronychia infection increased extensively during plasma electrolysis of water type experiments. Among of the factors affected the skin structure was thermal diffusion. This factor had a crucial role not only in producing the acute paronychia infection but other severe thermal injuries also. The other factors which could have a source of said infection were thermal currents and thermal fluxes. The sites of conduction heat current and conduction heat flux were important as compared to the convective and radiative heat currents and fluxes.The electrolytes were the other supports which irritated the epidermis.In order to circumvent these types of hazards, preventive measures are necessary for the researchers and other industrial workers.

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