A THREE LAYER POROUS MEDIA MODEL OF CUTANEOUS CIRCULATION WITH APPLICATION TO MECHANICAL SKIN IRRITATION

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Summary Scratching skin induces vasodilatation on the line of stroke and in the surrounding tissue. Vascular network has been described using a model consisting of three layers. First and last layer presenting irrigation and drainage of the system, are described as horizontal bidimensional porous media. Intermediate layer, described by means of compartments, does not allow horizontal fluxes. Mechanical skin irritation is modelized by changing compliance of vessels situated at the entrance of microcirculation.

INTRODUCTION

Already in 1927 Lewis [4] described skin reaction to scratch. He distinguished three different reactions. The first one, local reaction, describes vasodilatation on the line of stroke, its onset taking place after a very short delay. The second reaction considers spreading of the zone of vasodilatation in the neighboring area after a delay of $20s$ to $30s$. Scratching skin leads to mast cell compression and pain receptor stimulation. Mast cell compression induces histamine release on the line of stroke. Stimulated pain receptors induce nervous signals which induces neuropeptide release in a region situated around the zone of scratching. Histamine and neuropeptides are vasodilatators.

Blood circulation has been described by different types of models. Muscle circulation has been studied by Braakman et al. [2] using compartment models (lumped parameter model). Here, mechanical behavior of each type of vessel is described by the resistance and compliance of one compartment. Huyghe et al. [3] propose to describe vascular networks using porous media. Vankan et al. [5, 6] describe muscle circulation by a model consisting of five layers. Each layer is defined by laws of porous media permitting horizontal fluxes. Exchange fluxes inbetween two layers are allowed taking in account correct physiological direction. Cutaneous vascular network and irritation has already been described using discrete model by Bauer et al. [1]. The model proposed here is inspired by the models of Braakman, Huyghe and Vankan. It shows description of vascular network as continous media. It will permit to study whether widening of the zone of vasodilatation is only due to nervous signals or whether a diffusion process, leading blood from the zone of stimulation into the neighboring areas, takes place.

THE MODEL

Vascular network has been described by a model consisting of three layers. First and last layer presenting irrigation and drainage of the system, are described as horizontal two-dimensional porous media. Intermediate layer, described by means of lumped parameter method, does not permit horizontal fluxes, taking in account the fact that cutaneous capillaries show only very few connections between themselves. Hierarchical fluxes are directed from first to second layer and then towards drainage layer considering physiological flow direction.

The model is based on a surface representation of skin while fixing constant value for depth. Consider a surface element $dS = (dx, dy)$ in which vascular network is situated. Blood flow in this element is defined by geometry of vascular network and pressure gradient between irrigation layer and system of drainage.

Formulation of volume balances for the point (x, y) of each layer, considering blood as incompressible, we obtain the following equations (ϕ_I: volume of irrigation layer , ϕ_M: volume of microcirculation layer, ϕ_D: volume of drainage layer)

$$\dot{\phi}_I = -div\vec{I} - \Psi_{I\to M} \tag{1}$$

$$\dot{\phi}_M = \Psi_{I\to M} - \Psi_{M\to D} \tag{2}$$

$$\dot{\phi}_D = -div\vec{D} + \Psi_{M\to D} \tag{3}$$

where $\vec{I}$ and $\vec{D}$ are spatial volume flow fields of the first and last layer. $\Psi_{I\to M}$ describes hierarchical volume flow between first and second layer. $\Psi_{M\to D}$ illustrates hierarchical volume flow between second and third layer. Volume flow fields $\vec{I}$ and $\vec{D}$ are described by Darcy's law using two-dimensional permeability tensors. Hierarchical fluxes $\Psi_{I\to M}$ and $\Psi_{M\to D}$ are given by Poiseuille's law applied to pressure difference between first and second layer and difference between second and third layer. Volume is supposed to be proportional to pressure by means of compliance. All permeabilities depend on volume. Irritation is simulated by changing compliances of vessels situated at the entrance of microcirculation. The model can be applied at macroscopic scale considering the system arteries, microcirculation and veins and at microscopic scale describing the behavior of arterioles, capillaries and veinules. All data for model parameters is given by Vankan et al. [5, 6] and Braakman et al. [2].

RESULTS

Fig.1 shows time dependency of volumes of stimulated points. Fig.2 shows difference between first and second equilibrium state of the somme of volumes of three layers. White zone corresponds to area of stimulation. Results are given for both scales. All results are normalized by volumes of first equilibrium state. One can note that change in volume in neighboring area is very small in comparison to increase in volume in stimulated points.

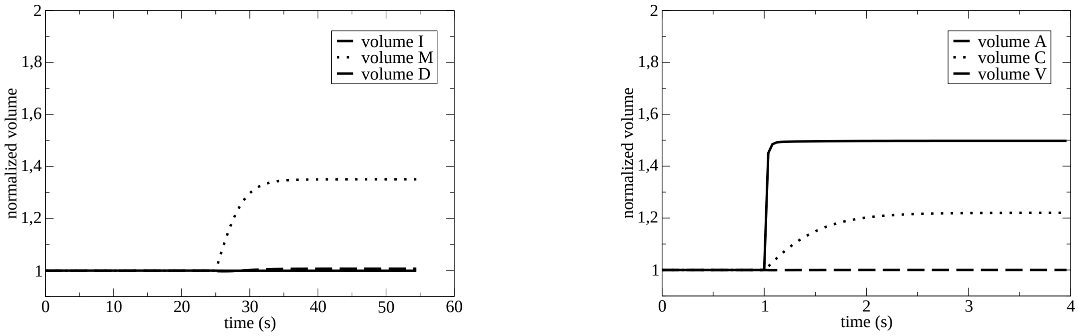

Figure 1. Time evolution of volumes of stimulated point (right: macroscopic scale, left: microscopic scale)

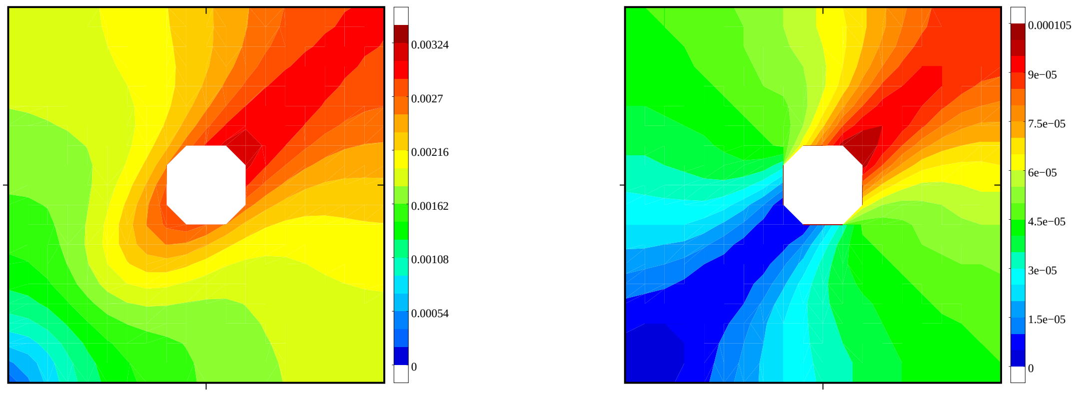

Figure 2. Difference in volume in neighboring area (right: macroscopic scale, left: microscopic scale)

CONCLUSION

Combining a two layer porous media model with compartment model permits to describe spatial and hierarchical fluxes in continuous media without the necessity to have information on geometric data. As the model can be used at different scales, it permits to investigate influence of irritation on microcirculation and total circulation. Vasodilatation taking place in the zone of stimulation corresponds to first reaction described by Lewis. Although volume does increase in the sourrounding zone, increase is not sufficiently high to explain vasodilatation due to nervous reflex. Thus the model is in accordance with Lewis theory. We can conclude, if widening of the zone of vasodilatation should be simulated, nervous reflex has to be modeled.

References

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