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A NON-LINEAR TWO-PHASE MODEL FOR SKIN AND SUBCUTANEOUS FATTY TISSUE.

C.W.J. Oomens, H.J. Grootenboer, D.H. van Campen
Dept. Mech. Engng.
Twente Univ. Technol.
Enschede
(The Netherlands)

INTRODUCTION

The purpose of our studies is to contribute to a better understanding of the cause of pressure-sores. To achieve this goal it is necessary to predict stresses and strains inside the tissues covering bony prominences due to an external load. For this we are developing a mathematical model of these tissues. The finite elements constituting the presented model can handle large deformations, non-linear materialproperties and time-dependent behaviour and can be used for skin as well as subcutaneous, fatty tissue.

THE MODEL

Both skin and subcutis contain an amount of free movable interstitial fluid. It is our opinion, shared by others (1,2) that this fluid is at least partly responsible for the time-dependent behaviour of the tissue and that it may play a role in pressure-sore-development (3). That is why a two-phase model is made in which the tissues are considered as incompressible porous solids with a free movable fluid in it. By means of an averaging procedure a continuum is defined for which equilibrium equations and constitutive equations can be derived. The motion of the fluid is described by the macroscopic law of Darcy. These equations are solved, using a Galerkin, weighted residual method suitable for a finite element model. All equations are written with reference to the undeformed state (total Lagrange). For the solid phase a relation between the 2nd Piola-Kirchhoff stress tensor and the Green strain tensor will be used as a constitutive law. We incorporate an exponential strain energy law according to Y.C.Fung (4). After writing the equations in an incremental form they are solved by means of a Newton-Raphson iteration procedure.

ANALYSES OF A TWO-LAYERED STRUCTURE

A qualitative study is done for a two-layered structure (skin and subcutis) on a rigid foundation (bone) loaded by a round indentor. Fig.1 shows the two-dimensional element mesh that has been used and the dimensions. At the boundary x=28 mm we have free drainage, all other boundaries are impermeable for the fluid. Because we were primarily interested in the two-phase behaviour linear elastic, isotropic material properties have been used (table 1). In two timesteps (=12 s) the load is increased to 6N and then held constant. Contact elements with infinite friction were used on the interface between indentor and tissue.

Immediatly after the load is applied the fluid will take up most of the load. Because of the high pressure gradient near the indentor (fig.3) the fluid will flow away from the indentor. Fluid pressure will decrease and the solid will take over the load. So the indentor will have an increasing displacement in time. When looking at the fluid pressure further away from the indentor one sees that its behaviour differs from that directly beneath it (fig.2). It rises to a maximum and then decreases, because the fluid needs some time to flow through the mixture and redistribute the pressure (see fig.3).

DISCUSSION

As has been stated by previous authors (2,5) and again demonstrated here, when measuring the "pressure" in the tissue, one has to be very carefull in defining this pressure. Moreover if fluid pressure is measured (for example with a Wick catheter), it is important to notice that this pressure strongly depends on time and place in this kind of situation.

The qualitative behaviour of the pressure in the kind of test, as demonstrated above, may lead to a way for in-vivo determination of the permeability of the tissue.

It is believed that several of the often remarkable mechanical properties of biological tissues may be explained when free fluid movement is included in the considerations and that the presented model gives a reasonably easy way of describing some of these properties.

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	E [Nm^{-2}]	ν	K [m^4/Ns]
	$X10^6$		$X10^{-13}$
Skin	0.395	0.128	1
Fat	0.153	0.243	4

table 1

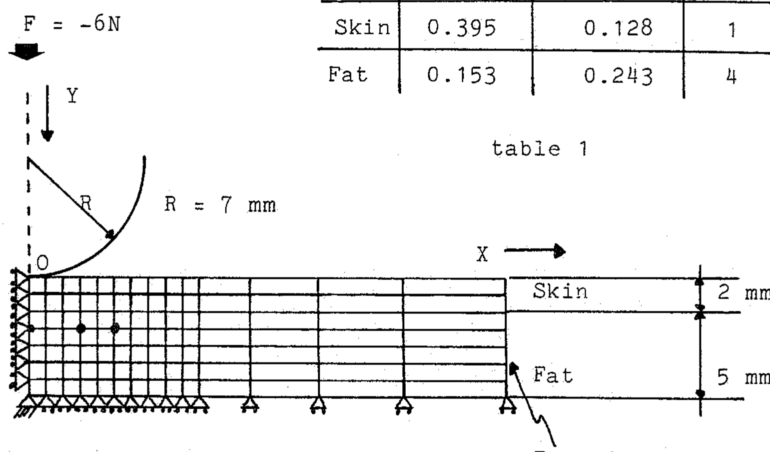

fig.1: Elementmesh

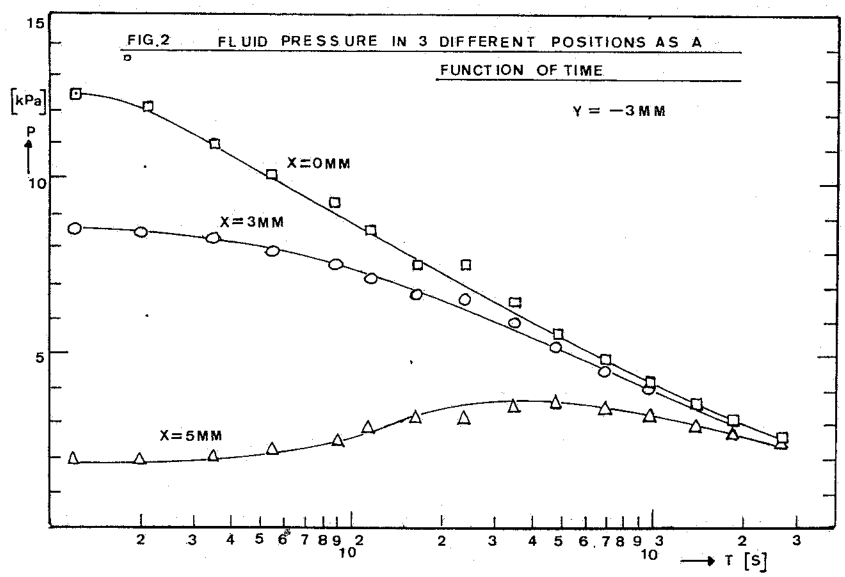

FIG 3.- FLUID PRESSURE AND DEFORMATION AT FOUR DIFFERENT TIMES.