Title: **Why human skin study is interesting for the Mechanical Research?**

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Abstract: Human skin has various functions, the mechanical one is the most important. From the mechanical point of view it shows an anisotropic and viscoelastic prestressed behavior. Actual research studies concern the prediction of the skin response according to different solicitations. So, the investigation methods are very useful and must be improved to qualify all the specificities of the mechanical behavior of human skin. The aim of this article is to present in logic way devices developed for characterization of human skin in vivo. From an extensometer developed by Femto-st, a device aimed at the determination of the state of initial tension was conceived, tested, denounced and then drove to study a system of original anchoring reproducing the adhesion of the ice-cold barrier.

Keywords: Human skin, prestress, extensometer, experimental device, thermal properties

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Introduction : Human skin as a material's study.

Human skin is the largest organ of the human body, it covers 2m² with 1mm thickness on average.It insures multiple functions (Agache 2000) at the interface between the human body and its environment: It plays role of barrier against the loss in water and the penetration of substances, It plays a role of thermoregulation, a neurosensory role and also photoprotection and immunity. It has a very important mechanical function: It protects against outside mechanical attacks in an important range of efforts, It is fitted to the modifications of shape and volume of the underlying organs and to the large movements imposed by the postures without almost any fold (except up to a certain age), It auto-repairs, its properties of surface allow the adhesion or suggest a extreme sweetness. These multiple roles lead to a multidisciplinary approach.

The skin can be considered as a composite multilayers. Its global behavior is viscoelastic anisotropic and pre-stressed (Agache and Varchon 2004) (Dellaleau 2007). Furthermore the skin is heterogeneous and the in vivo human skin constitutes a living tissue: the tissular regeneration is perfect if the zone to be covered is not too important. It is activated and amplified by the gradient of properties in the limits of the edge of the wound. The adaptation of the tissue in the conditions of use and the optimization of the properties according to the solicitations are proofs of this complexity. The link between the fact that the skin is a living tissue and its mechanical properties was not demonstrated yet. It is necessary to understand it to predict the evolution of the tissue.

Who is interested in the mechanical study of the skin ?

That is why the mechanical approach of the skin as the material of study is interesting for the doctors and the surgeons, for the cosmetologists and also for the engineers: indeed, the mechanical approach helps in the diagnosis and thus in the preparation for the care. It is useful as optimization of the techniques of sutures since the modeling is realistic. The preliminary knowledge of the tissue behavior and its state of prestress in the zone of interest is indispensable to develop cutaneous substitutes. The study allows the development of medical techniques adapted for the skin conditions, for instance the pressotherapy. The control and the evaluation of the efficiency of cosmetics or dermatological creams are direct applications, as well as the evaluation of the sensory properties of the skin. Finally, engineers are interested in mechanical properties of the skin to make better products such as “soft” but “closely” razors , or pleasant touch surfaces or “second skin” technical tissues or still robots.

During the last years, the department of applied mechanics of the Femto-st Institute developed several experimental devices to determine the intrinsic mechanical behaviour of the in-vivo skin. These works followed upon a mechanical characterization of ex-vivo tissue obtained from stomach plastic surgeries. This study demonstrated its limits as for the understanding of the involved phenomena (Vescovo 2002).

Material and methods for mechanical characterization

The first case, a mechanical device (represented on figure 1.) combining a mechanical uniaxial loading, an acquisition of the involved stresses and an optical acquisition of the strain field on the skin surface was developed within the framework of a collaboration between the University of Franche-Comté (Femto-st and CHU)) and the Pierre Fabre Research Institute.

The mechanical loading is obtained thanks to classical micro-engines (direct currents) which allow the relative movement of two pads placed on the surface of the skin and enslaved independently in force or in movement (Labview ® and inductive displacement sensor). The recorded loads are measured with a cantilever beam equipped with micro-strain gauges. The position and the orientation of the loading with regard to the tissue to be qualified are screened by a 360° rotary system, what allows to determine the anisotropy and the heterogeneousness of the tissue.

The device is fixed to the frame. The fixation of the device on the surface of the skin brought through the adhesion of clamps that are sticked by suction. The sensibility of the cantilever beam makes possible force measurement until 0,01N.

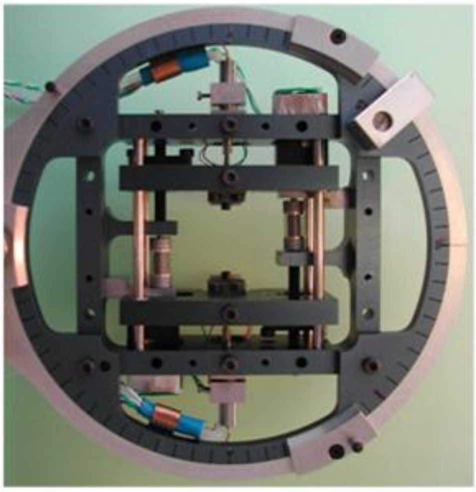


Figure 1 : uniaxial extensometer device (P. Vescovo)

The second complementary study allowed to create an original device [Jacquet et al. 2008] named " 4 pads ". This device allows us to determine experimentally the state of initial tension of the tissue by imposing a relative closer moving of both pads on the surface of the skin (figure 2.). To avoid the important mechanical effect of the zone outside the study area, two following pads were introduced on both sides of the measuring pads. The load recorded on the blade in flexion and displacement enslavement allowed to quantify the initial tension corresponding to an effort level independent from the elongation of the tissue.

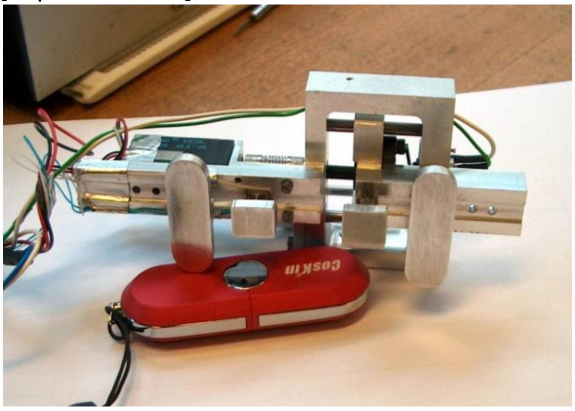


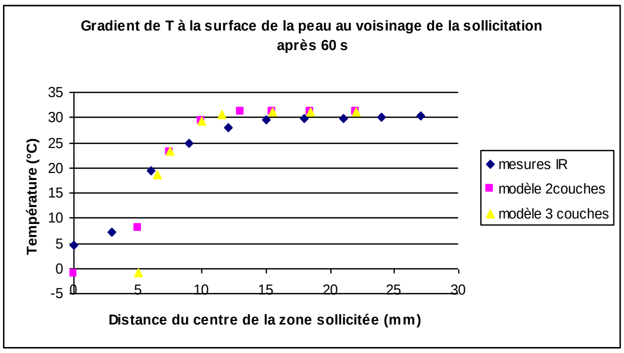
Figure 2 : « 4 pads » device

A specific study of the device´s anchoring on the surface of the skin led to validate a new concept. The concept of cryogenic anchoring: it ~~a~~ means to reproduce the adhesion of the ramp frozen in winter which cools an area of the tissue on the surface of the skin and stiffens in depth a part of the thickness of the tissue. The anchoring is realized by a cooling system equipped with thermoelectric elements with effect Peltier and temperature enslavement. The originality of the system is in the fact that the system adapts itself to the tissue which undergoes this thermal loading, the exchanges with the surrounding air and the metabolism of thermal regulation which keeps a constant body temperature at 37°C.

The validation of this anchoring system was proved by mechanical tests of anchoring resistance and by a numerical study. The aim was to determine the temperature field in the tissue from measure IR and by tests showing its use when putted on a extensometer device. The tissue was modeled as one multilayers with specific thermal properties (Agache 2000) ($k_{epidermis}$=0,2W/m°C thickness:0,06mm); (k_{dermis}=0,5W/m°C thickness:1mm). The thermal loading is represented by a heat extracting on the surface of the tissue (T =-1°C). The exchanges with the surrounding air are modelised as convection with the air in 20°C ($h=5.10^{-3}$W/m) and the metabolism as a convection with the 37°C blood at the bottom of the dermis ($h=1,5.10^{-2}$W/m).

Results :

Tests with the extensometer on one hundred patients were realized at Pierre Fabre research institute and showed the high variability of the behavior in extension, relaxation and creep. All the measures were done at the forearm and a precise protocol was elaborated to allow a comparison of the experiments (Khatyr et al. 2004). It shows the necessity of introducing the natural tension of the tissue into modelings to predict the effects of the loading on the tissue . This initial state of tension quantified indirectly by various authors (Diridollou 1994) (Yoshida et al. 2001) is difficult to measure on the skin with the proposed device nevertheless validated on sample of elastomer [Jacquet et al. 2008]. One of the explanations of these difficulties concerned the connection device-tissue limited to the surface and not allowing to relax all the depth of the tissue. The cryogenic anchoring was developed for avoiding this problem.



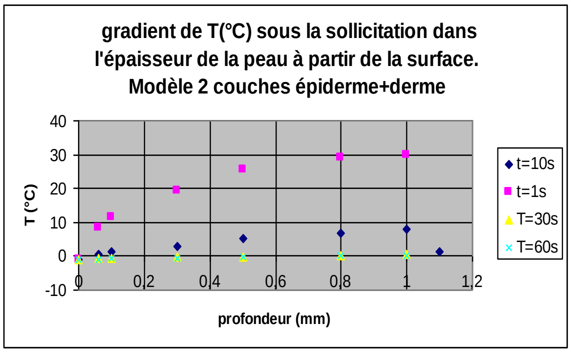


Figure 3 : Gradient of temperature according to the distance to the perturbed zone. a: at the level of the surface after 60s. b: in the thickness of the skin from the surface.

The mechanical holding of the cryogenic anchoring in the direction perpendicular to the surface is upper to the resistance of the tissue. In the plane of the tissue, we show that the anchoring resistance is up to 170KPa. In the thermal modeling the parameters of the tissue were fitted from the measures IR of temperature fields at the surface of the tissue (figure 3.a). The kinetics of the temperature exchanges lead to a field calculated in the thickness of the tissue (figure 3.b.).

The results of this modeling show that the cold pad spreads very quickly (less of 30s) a zone (of 1mm of thickness) at a frozen temperature. So, this limits its use to anchor a device of mechanical tests on the in-vivo human skin because those tests often require a longer tests time. And although the cryogenic anchoring brings numerous advantages for biological tissues (Vescovo 2002), this technical solution will not be retained for the fixation of our devices.

Discussion :

The investigated solutions must be revised to preserve the integrity of the tissue and respect the rules of ethics fixed by the sanitary authorities for clinical tests. However the load applied ~~to~~ directly measure the state of natural tension of the tissue are not vain: we aim our work~~s~~ to the development of an cycling loading extensometer today. This device will bring the possibility of isolating the intrinsic behaviour of the material from the environment test conditions and to distinguish the elastic part and the viscous part of the behaviour. The initial tension of the tissue is one of these environment conditions and can be directly measured by the temporal answer of the tissue to a suitably chosen loading.

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