Some Mechanical Properties of Skin

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The most obvious function of skin is its performance as a barrier, i.e. to keep organs and tissues inside and to prevent the entrance of foreign materials. On a more or less molecular level skin is composed primarily of collagen bundles with a small amount of elastin (4%) and about 20% other "ground" materials. This is a fibrous three dimensional network which is anisotropic in nature both in its response to environmental change or mechanical forces. Because of the size (mass) of the internal organs and of the force of gravity, there is tension on the skin which is unequally distributed.

The observation that a wound is not an exact replica of the device which made the penetration was noted in the early 19th century by the French surgeon Baron Guillaume Dupuytren (1777-1835) [1]. In examining an assault victim, he found that the stab wounds made by a stiletto were more linear than round and not as he had expected. Experiments on cadavers confirmed this phenomenon. His observations were considered to be important both forensically and surgically and were reported in the books on surgical practice by the noted French surgeon and scholar Joseph F. Malgaigne (1806-1865) [2]. This information was widely disseminated through several editions of this standard text.

The first systematic published study of the configuration of the tension on cuts in the human body was made by the Austro-Hungarian anatomist Karl Langer (1819-1887) [3]. The technique that Langer used was simple and elegant. He had a sharp circular awl that he used to make holes in the skin of cadavers. In areas under tension, the holes were not circular but oval in shape and when the major axes of the ovals were connected, a picture of the lines of tension in the body was developed. Figure 1 shows a detail of the type of data that Langer produced. These contours clearly showed that all points on the body were not equivalent in tension and, hence, any penetrations made into the body would be distorted by the direction and tension along or across these lines. It should be noted that not all lines will be of equal tension.

Further research into these patterns in human skin was carried out by H. T. Cox [4] and published in 1941. Cox made over 22,000 puncture wounds in 28 cadavers and from this data developed contours of tension similar to Langer's lines. From the works of Langer and Cox an atlas of these lines may be compiled.

Aside from the fact that the Langer's lines show how the skin naturally accommodates the large relative motions of the body's different components, the surgical significance of these lines has been ably summarized by Cox [4]. The existence of an organized directional structure to the connective and elastic tissue fibers of skin was demonstrated by examining cross sections of skin along and across the Langer's lines. The conclusion may be drawn that more damage is done to the skin tissue by cutting across the fiber bundles (i.e. across the Langer's lines) than along the lines. From a surgical viewpoint then, incisions along the lines leave fine scars on healing while those cut across will leave widely stretched "unsightly" scars. This happens because there is less tension pulling sideways against a cut along the Langer's lines and thus, less tension on stitches and a lesser tendency for the wound to gape [5]. The converse is true with cuts and stitches across the Langer's lines. Tension along these lines varies with sex and with obesity and, of course, with the location on the body. The strength of the skin is usually greater parallel to the Langer's lines rather than perpendicular to it [6]. Sections of skin cut from a body will also contract to a greater degree along the directions of the Langer's lines.

Description of the mechanical behavior of the skin depends on a little engineering background. First, we must define some terms. Stress is the force per unit area and has been traditionally expressed in pounds per square inch. Strain is the distance a material is stretched divided by the original length of the material. Strain is expressed as a unitless quantity or when multiplied by 100 is denoted as per cent elongation of the test specimen. If a material is monitored when stretched, the stress developed can be plotted against the strain and this becomes the standard engineering stress-strain plot. Figure 2 shows the stress-strain plot for vegetable tanned goat skin which is similar to human skin and figure 3 shows the stress-strain curves for a sheepskin parchment (prepared skin) tested through a series of angles about the direction of the collagen fibers or "grain". Figure 2 shows an initial shallow increase in the stress of the skin as a force is applied with an increasing stiffness and stress development as further force is applied. This is the so-called J-shape curve and is often found in a greater or lesser degree with collagenous materials. The rate of change of the curve (the derivative of the stress per strain) is an indication of the flexibility of the skin. The shallowness of the initial stress-strain curve indicates the reason that at small displacements or stretching the flexibility of the skin is quite large. As the curve becomes steeper with increasing load or distance, the flexibility of the skin decreases.

An interpretation of this behavior can be postulated. Microscopic examination of sections of skin along and across the Langer's lines shows a preferential orientation of the collagen fibers of skin. The orientation seems to be at an angle a bit less than 45 degrees from the direction of the lines. This insures a mechanical response which is anisotropic when force is applied.

The model for the behavior of skin (leather, vellum, parchment etc.) proposes a "chicken wire" or mesh orientation of the collagen fibers in skin. This is illustrated in figure 4. Any tension along the network of the mesh will have an initial region where low forces will be taking up, or orienting, the fibers along the force axis. As this slack is taken up, the forces will act more directly on the collagen fibers themselves and the effect will be a stiffening and a significant increase in the stress levels required to deform the material. This is what is seen in figure 2, the goat skin, where after initial displacements the stresses increase geometrically with increasing strain. The degree to which this is observed is probably related to the methods by which skins are prepared. In figure 3, the parchment data, the stress strain plot shows an initial high rate of stress development. It is entirely possible that high stretching stresses during the curing and preparation of the parchment performed much of the initial low level fiber orientation. Work applied to skin, leather, or parchment affects the mechanical properties even when there appears to be no stress on the material. The tests do, however, confirm Langer's observations that the tension (stress) in skin is highly dependent upon the direction of measurement within the skin. After differences due to initial orientation are removed the mechanical properties do, however, become quite similar.

The mechanical properties of living skin can vary in certain disease states and changes in the elastic properties occur with age. The cross-linking of collagen seems to be involved in these processes but not in a simple fashion.

From a practical standpoint, the skin structure with its interesting mechanical behavior indicates that the response to penetration will vary according to the orientation of the collagen fibers and with their tension. The body area where the puncture takes place dictates the shape of the wound. Cuts from the same instrument can appear as almost a line in one location and as an ovoid shape in another. The size and cross-section of the instrument can be ascertained only from a knowledge of the applied direction of the penetration and its body location with its relative tension.

Similar discussions can be had concerning the behavior of cuts in other materials in tension such as clothing textiles [7].

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Figure 2. The Stress-Strain Curve for Vegetable Tanned Goat Skin.

Figure 3. The stress-strain Curve for sheepskin parchment through various angles and showing the similarities in behavior after an initial adjustment in the direction of the grain.

Figure 4. Graphical description of the wire-mesh model for collagen fiber bundles in skin.

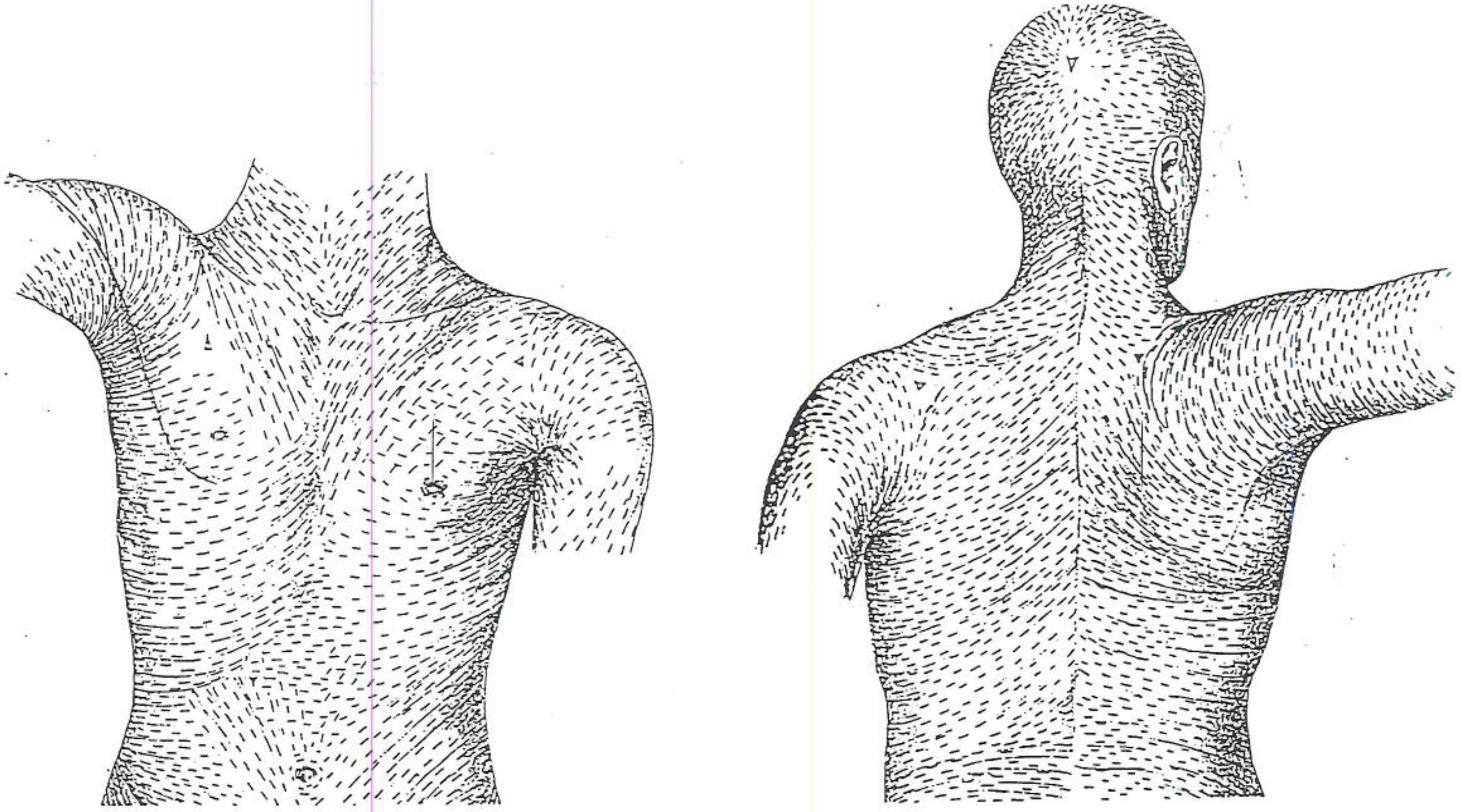

Figure #1) The patterns of the lines of tension in the human torso. (after Langer 1861)

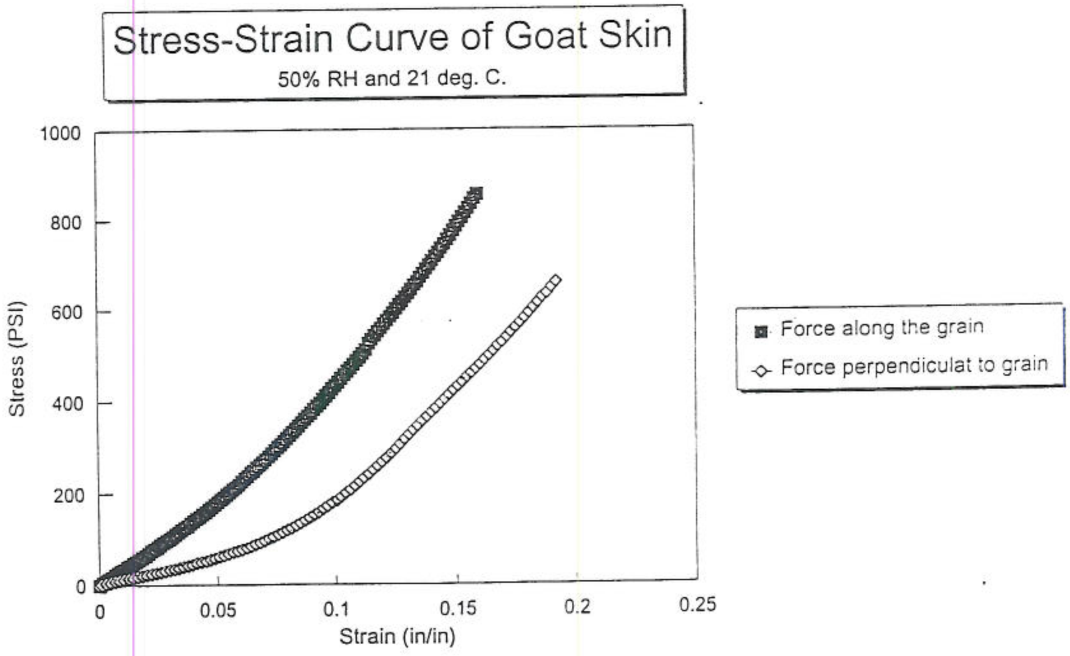

Figure #2) The stress-strain curve for vegetable tanned goat skin.

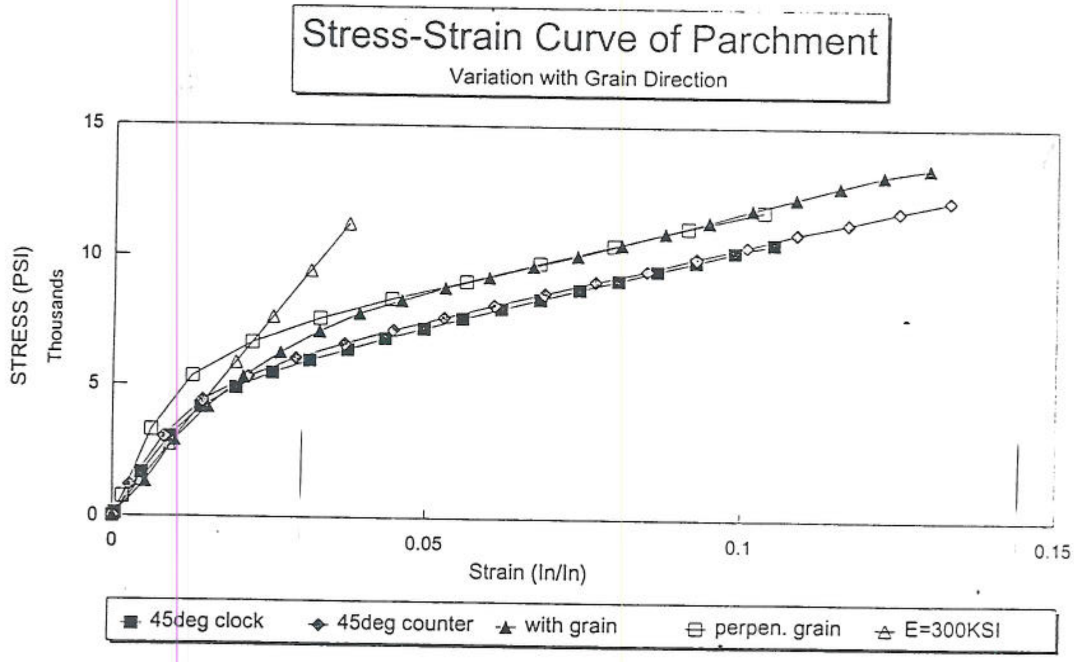

Figure #3) The stress strain curve for sheepskin parchment through various angles and showing the similarities in behavior after an initial adjustment in the direction of the grain.

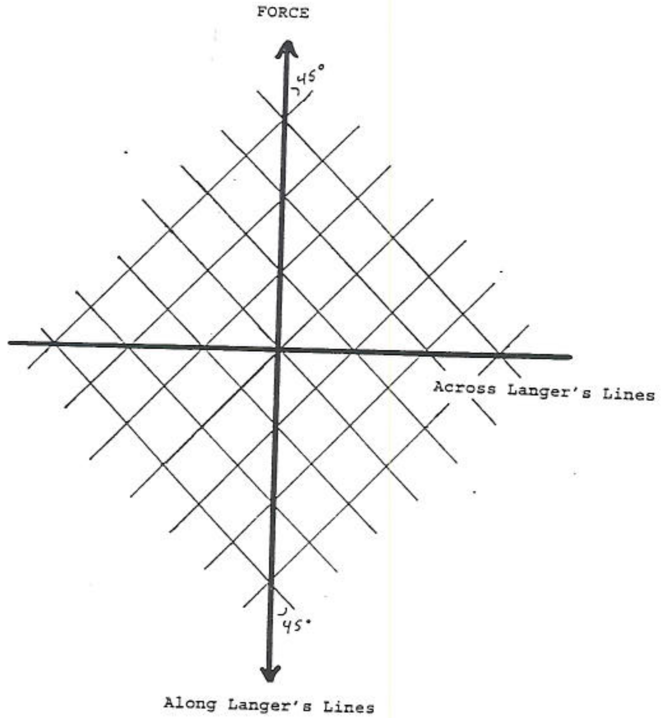

Figure #4) Graphical description of the wire-mesh model for collagen fiber bundles in skin.