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# A comparative study of frictional response of shed snakeskin and human skin

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ABSTRACT

Skin in biological systems, including humans, perform several synchronized tasks (mechanical, protective, tactile, sensory, etc.). Tribological function is among skin tasks and may determine the survivability of many species. Cross comparison of tribological functional traits of skin of different species, albeit interesting, is rarely encountered, if at all exists, in tribology literature. One interesting example is that of snake and human skins. This skin pair was the subject of many studies for transdermal drug delivery. Results in that context concluded that snakeskin is highly compatible with human skin despite apparent differences in surface structure and topology. The reported compatibility raises curious question of whether there exists frictional or tribological compatibility between the two skins and if so, under what conditions, and which context. In this work, we report, for the first time in open literature, results of a comprehensive comparative investigation of shed snakeskin and human skin with respect to tribological behaviour. To this end, we compared the frictional response of shed skin obtained from P. regius and human skin from different anatomical sites, gender, and age. The results imply that, in essence, the mechanisms governing the friction response of human skin are common to snake skin despite difference in chemical composition and apparent surface structure. In particular, both skin types display sensitivity to hysteresis and adhesive dissipation. Human skin, however, being more sensitive to hysteresis than snakeskin. One interesting finding of the study is that the ratio of the coefficients of friction for snake and human skin, when sliding on the same interface, depends on the reciprocal of their respective moduli of elasticity.



## 1. Introduction

Skin in vertebrates and inter-vertebrates manifest complex composition. It comprises arrays of collagen fibers arranged in various patterns. Arrays of collagen and elastin are common in skin of many species (human, worms, fish, etc.,). Collagen fibers assume several shapes (straight, convoluted, or crimps). They are arranged in patterns of various degree of randomness [1] Despite sizeable variation in structural patterns, the stress strain curve of almost all skin types is of a universal form (the so-called J-shaped stress-strain curve) [2].

Mai and Atkins [3] analyzed the energetics of the J-curve at each interval of its evolution during tensile tests. They observed that within the early stages of this type of stress-strain curve, strain is almost independent of stress. This implied the lack of shear connection in the particular material. Lack of shear connection prevents the concentration of energy into the path of a putative crack. Lack of shear connection, equivalent to lack of shear stiffness in anisotropic solids, is the origin of high tear resistance of skin [3].

Friction is an interfacial phenomenon within which a shearing force performs work on an effective volume of two complying materials. This effective volume includes the surface layer of the skin as well as several sublayers that support the normal complying load. Dissipation of the friction-induced-work takes place within the sub-layers along a path that depends on the pattern of the fiber-elastin matrix comprising the skin. The universal behavior of the stress strain curve for the skin implies also a universal behavioral trend in shear loading and thereby in friction. That is one may anticipate that the mechanics of accommodation frictional loads in skin are universal regardless of the species.

In the past three decades or so, considerable work that probe

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**Nomenclature**

| | |
|---|---|
| $A_{real}$ | Real area of contact |
| E | Modulus of Elasticity $Nm^{-2}$ |
| E* | Composite Modulus of Elasticity $Nm^{-2}$ |
| $E_H$ | Modulus of Elasticity for human skin $Nm^{-2}$ |
| $E_s$ | Modulus of Elasticity for snakeskin $Nm^{-2}$ |
| $E_c$ | Composite modulus of elasticity |
| $F_{ad}$ | Adhesive component of friction force |
| $F_{fr}$ | Friction force |
| $F_{int}$ | Interfacial component of friction force |
| $F_{def}$ | Deformation component of friction force |
| P | Contact force |
| R | Composite contact radius in Hertzian contact theory |
| $R_q$ | Mean arithmetic value of profile roughness (μm) |
| $R_s$ | radius of asperity |
| Sa | Aerial Mean arithmetic value of roughness (μm) |
| $S_{ku}$ | Profile Kurtosis parameter |
| Sq | Root mean square average of the roughness profile ordinates (μm) |
| $S_{sk}$ | Profile skewness parameter |
| W | Normal Load |

*Acronyms*

| | |
|---|---|
| SEM | Scan Electron Microscopy |
| COF | Coefficients of friction |
| RMS | Root Mean Square |
| TBH | Trailing Body Half |
| WLI | White light Interferograms |

*Greek symbols*

| | |
|---|---|
| $\gamma$ | Shear strain |
| $\nu$ | Poisson's ratio |
| $\mu_B$ | Coefficient of friction in backward motion for snakeskin |
| $\mu_F$ | Coefficient of friction in forward motion for snakeskin |
| $\mu_{Dry}$ | Coefficient of friction in dry sliding for human skin |
| $\mu_{Wet}$ | Coefficient of friction in wet sliding for human skin |

*Subscripts*

| | |
|---|---|
| H | Human skin |
| SB | snake backward direction |
| SF | snake forward direction |

friction behavior of human skin took place. The general motivation of these efforts varied between cosmetics [4–8], healing of burn and wounds [9–13], prosthesis [14–16], and haptics [17–21] among other things. Understanding the sense of touch and reaction of skin to fabrics was another major motivation [22–27]. Recently the problem of developing synthetic skin assumed considerable momentum. Several works that compare the friction of human skin to several synthetic skins started to emerge in the literature [28–34]. Tribology literature however still lacks studies where the friction behavior of skin from different species is cross-correlated. In fact, few studies that consider skin of animals or reptiles is not frequently encountered to start with. Of the existing studies, only few animal skin have been investigated (e.g. few reptiles, porcine and rat [35–42]). Cross correlation of human skin performance to performance of other skin types is a very active topic within transdermal drug delivery.

A primary objective in the design and optimization of dermal or transdermal drugs is to understand the mechanics of "in-vivo" performance. When the drug is designed for humans, it is essential evaluate percutaneous absorption of molecules. The best prohibit experimentation with human subjects within the initial development stage. A challenge, therefore, arises since the option at this stage is to find a plausible correlation between "ex-vivo", animal and human studies for prediction of percutaneous absorption in humans [43]. Consequently, considerable investigations took place within the past four decades to assess the permeability of many biomaterials in comparison to human skin. The list includes, primates, porcine, rodents, guinea pigs and snakeskin (with porcine skin being frequently showing many similarities to human skin [44–51]).

*Higuchi and Kans* [52] were the first to propose shed snakeskin as a barrier membrane in-vitro permeation studies. Following their lead, several researchers incorporated shed snakeskins in their experimental protocols. Skin from several snake species, Elaphe obsolete [53–57], have been investigated. *Haigh et al.* [58] investigated the effect of species, sites and body regions of the shed snakeskin on measurements and their relation to actual performance of human skin. Haigh reported good correlation to human skin. He suggested the use of shed snakeskin as a model membrane for permeation studies despite anatomical differences and chemical compositions [54,55,59].

Trans-dermal diffusion is a time-dependent phenomenon that initiates at the skin surface (i.e. at the level of the micro-topography (roughness)). The process starts by the diffusing substance attempting to occupy the void space between the roughness features of the target surface. Roughness features (or micro-topographical features on the skin) have no regular or uniform geometry. Spacing between, roughness features, volume occupied by an individual feature, and shape are all different on any surface. These parameters affect the path and time of diffusion through affecting the resistance to initially filling the void space. It follows that the manner the roughness features branch to occupy their respective volume in space will determine the void volume available for the diffusing substance to occupy, and thereby initial resistance to diffusion. That is, the layout of the micro topography features on the surface of the skin maps initial resistance to diffusion. Compatibility of diffusion between two surfaces (or skin types) therefore should originate from common features in the branching of roughness.

One difficulty encountered in identifying potential common metrological features is the appearance of the surface of both skin types. Abdel-aal [60] avoided this difficulty by considering the fractal structure of both skin types. That is by focusing on the growth of topographical features in space rather than on the statistical variation within the topography of the two surfaces. The analysis, thus, focused on identifying the relationship between form and volume in space then relating the findings to particular metrological features (i.e., the fractal description of the two skin types). Examination of exuviae of some 45 snake species and comparison to human skin verified that both skin types, despite displaying different surface topological features, share a narrow band of fractal dimensions ($2.55 \le D \le 2.6$). Sharing the fractal dimension explained the time compatibility of snakeskin to human skin observed in permeability experiments.

Sharing a common form of a stress-starin curve and a fractal dimension points at possible generalized tribological features