Biotribology 6 (2016) 21–28

Contents lists available at ScienceDirect

Biotribology

journal homepage: http://www.elsevier.com/locate/biotri

# Influence of the relative humidity and the temperature on the in-vivo friction behaviour of human skin

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ARTICLE INFO

*Article history:*
Received 12 January 2016
Received in revised form 17 March 2016
Accepted 18 March 2016
Available online 31 March 2016

*Keywords:*
Friction
Human skin
In-vivo
Relative humidity
Temperature
Pressure ulcers

ABSTRACT

Both temperature and relative humidity are known to influence the frictional behaviour of human skin. However, literature does not completely cover to what extent both parameters play a role. Measurements were conducted using an in-house built reciprocating tribometer inside an enclosure in which both the humidity and the temperature can be controlled independently. Friction measurements were performed in varying climates ranging from 25 °C and 40% RH to 37 °C and 80% RH at respectively 3 °C and 10% RH intervals. Using the obtained results a '*friction map*' was created which shows that the coefficient of friction increases by a factor of two when the environment is changed from 'cold and dry' to 'warm and moist'. A statistical analysis shows that the product of the temperature and relative humidity appears to be the driving factor describing the observed frictional behaviour. Results indeed show a more pronounced effect of either parameter at the warmer, moister conditions, in contrast to the colder, drier conditions where a smaller effect on the coefficient of friction is observed. The findings will be of importance, e.g. for bedridden patients who are prone to pressure ulcer development as it indicates the importance of maintaining a healthy microclimate.



## 1. Introduction

Each day the human skin interacts with a wide range of surfaces, of which textiles are among the most common. The way the skin interacts with such counter surfaces is not straightforward and depends not only on skin and counter surface characteristics, but also on the environment in which the two surfaces interact. The environment is an important parameter as it has an effect on the production and evaporation of sweat, the formation of capillary bonds and on the mechanical properties of the skin. The effect of changes in climate conditions are especially clear when comparing a warm, damp summer day, when clothes tend to stick to the skin with a cold, arid winter day, during which the skin becomes drier and more fragile. Despite the practical relevance, the exact and separate effects of the temperature and relative humidity on the contact and friction behaviour of skin have not been completely discussed in literature.

The microclimate around the skin depends on several parameters, of which the temperature of the skin and environment, physiological activity, and the insulation provided to the skin (such as the amount of clothing) are the most important. Kwon and Choi found that the temperature of the microclimate surrounding the human torso varied from 29 °C to 32 °C when the ambient temperature was increased from 14 °C to 29 °C [1]. The relative humidity in the microclimate depends on the insulation, as well as on the physiological activity and the relative humidity of the ambient air. Indoors the relative humidity typically ranges between 40% RH and 60% RH and in a clinical setting where a patient is located in bed, the temperature and the relative humidity at the skin-bedding interface can locally reach up 37 °C and 100% RH, respectively [2]. This increases the metabolic demand of the skin and the skin becomes more prone to damage such as pressure ulcers [3]. For bedridden patients a microclimate with a humidity of 40% RH to 65% RH is advised to reduce the risk of skin damage [2,4].

There have been several studies into the combined effects of increasing temperature and relative humidity on the frictional behaviour of human skin [5–10]. Hendriks et al. compared the coefficient of friction at 21 °C and 38% RH with 28 °C and 82% RH. They showed that the coefficient of friction increased by a factor of two when the climate conditions changed from 'dry and cold' to 'humid and warm' [6], but the individual effects of temperature and relative humidity were not studied. Gerhardt et al. showed that the coefficient of friction more than doubled when skin was rubbed against wet textile compared to the dry situation [11]. Based on the statistical correlations within a large experimental dataset, Veijgen indicated a strong proportional relationship between the ambient temperature and the coefficient of friction as well as a minor but statistically significant inverse relationship between the skin temperature and the coefficient of friction. The relationship between relative humidity and friction was more complex as no direct statistically relevant correlation was obtained, but indirectly an increased relative humidity results in a statistically significant increase of the skin hydration, which in turn increases the friction [8].

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http://dx.doi.org/10.1016/j.biotri.2016.03.003
2352-5738/

The consequence of humidity on the friction in the contact is not directly obvious. Theoretically, in a humid microclimate the evaporation of sweat into the air will be reduced, eventually resulting in increased wetting of the surfaces. This will both soften and plasticise the stratum corneum, the uppermost layer of the skin [12]. Softening or, more accurately, a loss of stiffness would mean an increased real area of contact at constant load, whilst plasticisation means a reduction of the interfacial shear strength. The coefficient of friction is proportional to the product of the contact area and the interfacial shear strength and it is hypothesised that the increase of the contact area is more pronounced than the reduction of the shear strength. As a result the coefficient of friction will increase with increasing humidity [12,13]. The effect on the skin of increasing the temperature is somewhat similar: most visco-elastic materials show a reduction in stiffness with increasing temperature, thereby increasing the real contact area when in contact with a counter surface [14,15]. Furthermore, at high temperatures the body increases sweat production in an attempt to control the core body temperature; the evaporation of sweat extracts heat from the skin, causing a cooling effect. In the case of a high relative humidity, evaporation is limited and skin moisture will start to accumulate in the stratum corneum [16].

The exact contribution of the relative humidity and the temperature and any possible interaction on the coefficient of friction in skin contacts is unclear. The aim of this paper is to extend our understanding of the effects of the environmental conditions on the frictional behaviour of skin.

## 2. Experimental

Friction measurements were conducted at a range of environmental conditions using an in-house built setup, as shown in Fig. 1. The setup consists of an enclosure in which both the temperature and the relative humidity (RH) can be adjusted independently. The enclose houses a reciprocating tribometer that measures the normal and friction forces between the probe material and the skin. Although a textile covered foam probe is in itself a complex material system and therefore not ideally suited for investigations aiming to understand the effects of the environmental conditions, this material was used as it is a common surface with which the skin interacts and therefore the results would have increased relevance over a simplified approach using e.g. a steel probe. Furthermore, the interaction between skin and textile is especially important for bedridden patients who are prone to tissue damage as a result of pressure and shear, such as pressure ulcers.

### 2.1. Experimental setup

The enclosure has outer dimensions of 400 × 500 × 300 mm, meaning the internal volume is about 60 l, allowing for precise control of the temperature and humidity climate whilst being sufficiently large to enclose a body part such as the lower arm. An elastic seal ensures a tight interface between the arm and the climate chamber. The temperature inside the climate chamber is controlled using a PID-driven 60 W enclosure heater and can be adjusted from room temperature to body temperature with an accuracy of 0.2 °C. The relative humidity is maintained by inserting dry air with a dew point of −60 °C in combination with an ultrasonic humidifier to increase the humidity to the required value. The relative humidity of the air can be controlled from 40% RH to 80% RH with an accuracy of 3% RH. A mechanical fan is used to create air flow, ensuring constant conditions in the enclosure.

Friction measurements are performed by repeatedly sliding a probe over the volar forearm, which is stationary positioned inside the climate chamber. Forces are measured using an ATI Gamma multi-axis force transducer with a force range in the normal direction of 200 N at a resolution of 25.0 mN, and a lateral range of 65 N with 12.5 mN resolution. The force transducer is mounted on a linear spindle drive by means of a hinged rigid beam, which is driven by a stepper motor (0.48 Nm, displacement: 1.3 μm/step). The rigid beam is free to rotate around the lateral axis so that the curvature of the arm can be followed. The normal load is set by using dead weights and a value of 0.5 N is used for the experiments.

### 2.2. Probe material

The probe is made of a polyurethane foam (E ~ 40 kPa) covered by a woven cotton fabric as shown in Fig. 2. Although cotton is also plasticised by water, Kenins found that the response of skin to water is the predominant factor in the friction [7]. The textile yarns have a diameter of approximately 0.3 mm and comprise a bundle of smaller

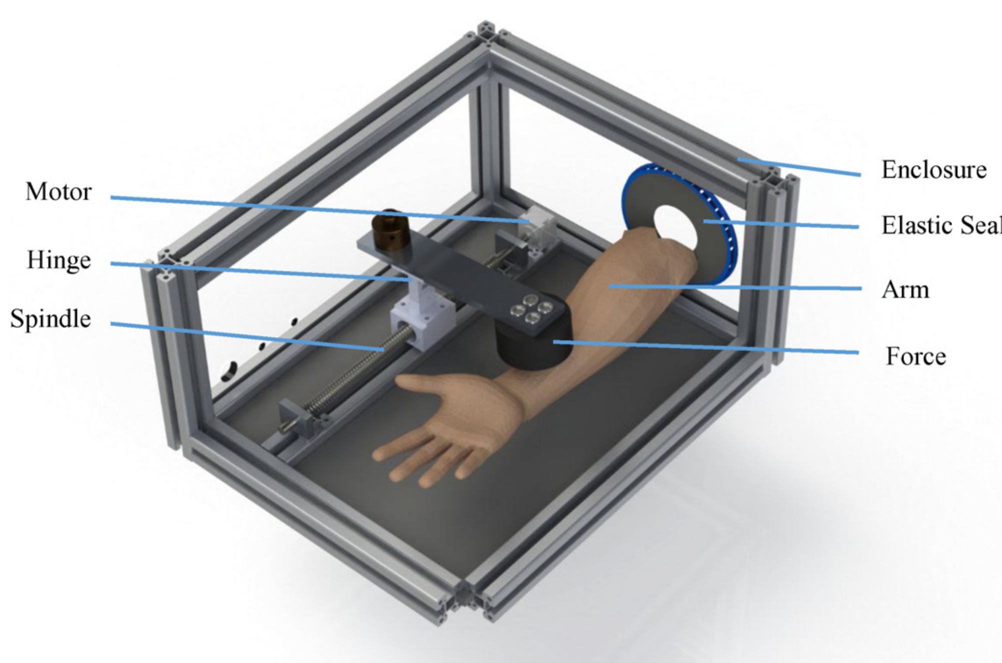


**Fig. 1.** Schematic view of the setup used for the friction measurements.