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Bio-Tribology of Incontinence Management Products: Additional Complexities at the Skin-Pad Interface

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Abstract

Friction, shear forces and moisture between the human skin and textiles are important factors affecting skin injuries such as blisters, abrasions and decubitus ulcers. Whilst much research has been conducted to study the friction of skin-textile couples, the interactions between contact mechanics and incontinence management products are not well understood. This study addresses some tribological issues at the skin-textile interface using skin care products. It was observed that the use of skin care products and moisture can increase friction. This is due to changes in the mechanical properties of materials such as their compliance and the higher forces required to shear the interfaces in wet conditions. It was concluded that not only does the coefficient of friction vary, but also the mechanism of slip at the interface can be modified through the addition of medicated creams. This research highlights the importance of understanding the principles of contact mechanics of interfaces which can lead to significant improvement in incontinence management.

Keywords: Skin tribology, friction, adhesion, stick-slip

Introduction

Urinary incontinence is a major problem affecting over 200 million people worldwide and up to 6 million people in the United Kingdom according to the NHS [1]. It is well accepted that such morbidities have a significant impact on both the physical and emotional quality of life for those with incontinence. The skin of an incontinent person is likely to be exposed to regular contact with urine, sweat and possibly faeces for prolonged period of time. The aggressive nature of the interfaces causes wound exudate or perspiration and disturbs the natural barrier function and eventually leading to skin breakdown. This is known as Moisture-Associated Skin Damage (MASD) [2]. This damage to the skin can cause further problems such as pain, risk of secondary skin infection, discomfort and distress for the patients [3].

The main risk factors regarding skin health for incontinent patients are well documented and methods to mitigate these are in clinical practice and outlined by NICE guidelines. In a review by Ersser et al [4], skin care strategies are discussed with respect to optimising the skin barrier function. A number of methods exist to manage incontinence, one of which is the use of absorbent pads. The use of moisturisation in conjunction with pads can help to protect and restore the skin from exposure to urine and faeces and reduce the risk of skin damage. However, this will result in a complex interface with the performance influenced by factors such as adhesion, properties of the skin, pad and any skin care treatment,. This is further complicated by the range of products and the nature of community care available for the treatment of incontinence. It has been reported [5] that some skin care products can potentially reduce the capacity of the incontinence pad to absorb fluids. This is due to inadvertent transfer of the barrier cream from the skin to the pad surface. On the other hand, Fleming et al [6] found that the reduction in absorbency for the skin care product is not huge when a barrier layer is present. Therefore, it was concluded [6] that the benefits of using these products compensated the reduction in performance of pads. This neglects that the skin-pad interface itself in systems with certain properties and characteristics occurring together, synergistically/ antagonistically.

Problems related to skin friction are an issue in both developed and developing countries across a huge range of clinical and everyday activities [7]. In recent years, there has been a significant interest on understanding the tribology of human skin. Skin is a non-homogenous, nonlinear and viscoelastic material [8, 9]. Therefore, traditional concepts of friction and application of data analysis for linear-elastic materials are difficult to apply [10]. This is further complicated by the many complex and multifactorial conditions which can be synergistic/antagonist depending on their operating environment. In daily life, human skin is in contact with a variety of materials during different activities due to labour, exercise, keeping warm, health and beauty needs, which cause many skin friction problems. Thus, the friction behaviour of human skin depends on the surface properties of skin, the contacting materials, contact pressure and presence of substances such as water, sweat and skin surface lipids at the interface as indicated by Figure 1 [11, 12].

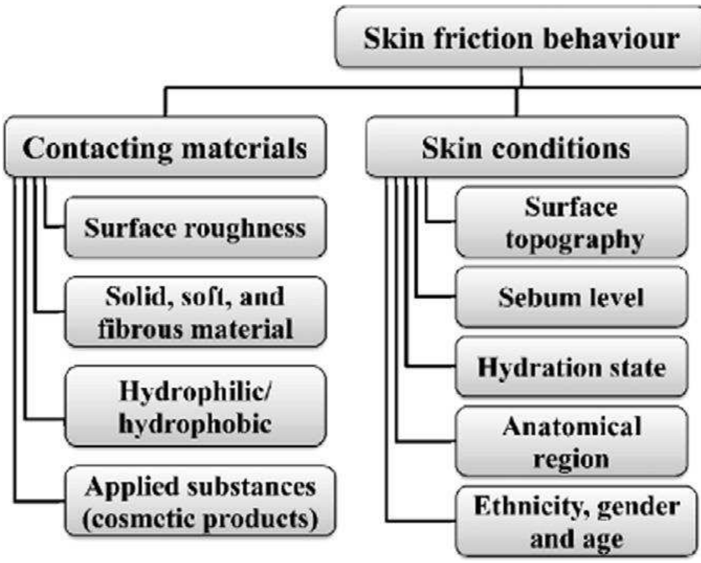

Figure 1 Some important factors that affect the friction behaviour of human skin [10]

Friction and shear forces, as well as moisture between the human skin and textiles are critical factors in the formation of skin injuries such as blisters, abrasions and decubitus ulcers [7, 9]. The prediction and understanding of the role of shear on skin health is therefore complex and likely to be interface dependent. Although there are few studies on different hydration levels with in-vivo skin friction, there is still no systematic study on the functional relationship between skin moisture and textile friction [13].

There has been much research on the friction of skin-textile couples, yet the interactions between contact mechanics and products used to manage incontinence are not very well understood. This study aims to understand the contact mechanics and friction behaviour of human skin using different skin care products in both wet and dry conditions. This helps to improve and optimise surfaces and materials that come in contact with the skin.

Experimental Materials and Methodology

Materials

Porcine skin was obtained from a local abattoir and used with 4 hours of sacrifice (John Penny & Sons, Leeds, UK). All skin samples were taken from the same area to ensure similar skin architecture and thickness throughout. Commercially available absorbent pads (TENA®, Sweden) were purchased from a local pharmacy. The skin care products were identified and selected based on feedback and outreach activity by IMPRESS network [13]. The main role of these product is to create a barrier between the skin, water/or other soluble irritants and textile to protect the skin. Details of these products can be found in Table 1.

Table 1. Skin care products used in the experiments.

Product name	Description
Conotrane	Silicone-based which contains: • Dimethicone: it is a silicone fluid| which is water repellent, • Benzalkonium chloride: it is antiseptic [14]
Medihoney	Honey-based which contains active leptospermum honey and glucose oxidase [15]
Intrasite gel	Aqueous gel which contains 2.3% carboxymethylcellulose (CMC) polymer together with propylene glycol (20%) [16]
Sudocrem	Water-based (consisting of oils/waxes) contains: • Hypoallergenic lanolin, to provide emollient properties • zinc oxide is an astringent which reduces the loss of tissue fluid • Benzyl benzoate and benzyl cinnamate for its healing properties • Benzyl alcohol is a weak local anaesthetic [17]

Friction measurement

To measure the friction between skin and textiles in this study, a bespoke modular skin friction test machine was developed as shown in Figure 2. In this test machine, displacement in the region of 5 µm to 15 mm and normal forces of 1- 10 N are achievable. Motion was actuated through a moving coil actuator (SMAC, USA) with the frictional forces spatially resolved using a low-load tension/compression load cell (RDP, UK) controlled using LabView software. Normal force was applied by placing dead weights on a hanger.

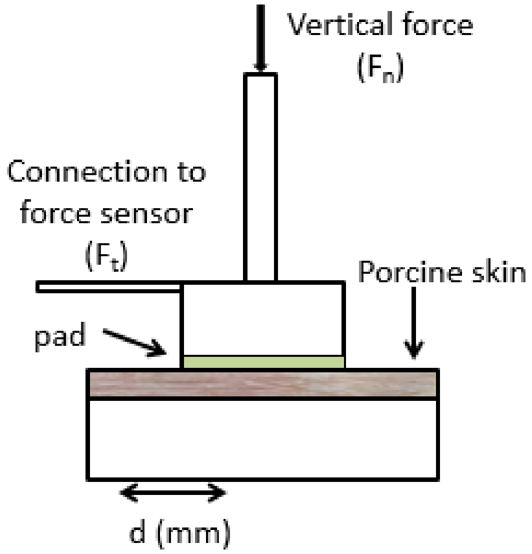

Figure 2. Schematic representative of a friction test principle used in this study to measure friction coefficient between a flat textile sample and porcine skin.

To facilitate friction measurements, Ø 50 mm samples were carefully cut from the absorbent pad and securely fastened to a polymer cylinder. This resulted in a flat-on-flat contact configuration (Figure 2). This was then mounted onto the reciprocating shaft which contained the tangential load cell. Skin samples were cut to size (50 x 50 mm) and cleaned with an acetone wipe. These were then placed within a stationary recessed holder and secured in place with acrylate adhesive. Tribological assessment was then conducted using the products outlined in Table 1 and parameters defined in Table 2. In these experiments, friction force was sampled at a frequency of 1 Hz over 60 s of sliding pad on the skin. Figure 3 shows a typical data of frictional trace over a 2 s sampling time. As shown in Figure 3, the mean value of friction force has been considered for the calculations and taken as the average friction force in the displacement independent regions of the friction force against time curves (ie gross slip). The friction coefficient (μ) was then calculated using the following equation:

$$\mu = \frac{F_t}{F_n}$$

Where

μ is the coefficient of friction,
F_t is the friction force, and
F_n is the normal force

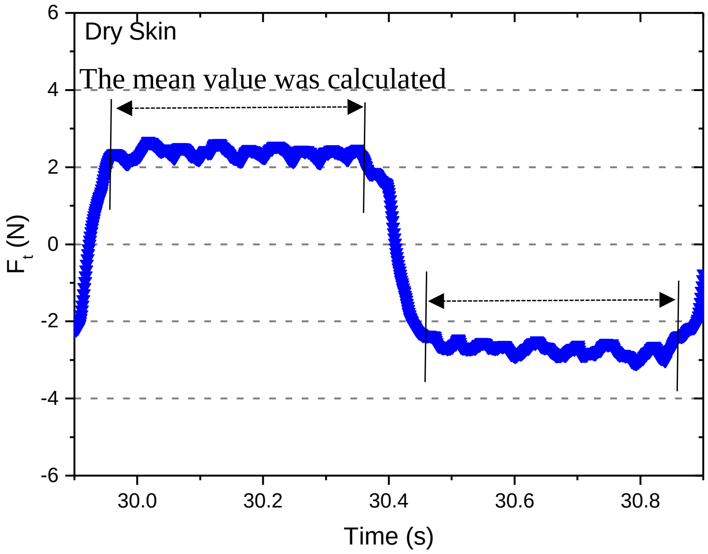

Figure 3 Time trace of the measured friction force

Table 2 shows the test conditions for the tribological test. Experiments were conducted in both dry and wet conditions at room temperature. 10 mL of deionised water (DI) was used to moisturise the surfaces. Four commonly used skin care products were used in this study to investigate the effect of individual products and the effects of dilution with water on friction of skin/textile contact. All experiments were conducted in triplicate (n=3) and appropriate results are presented as experimental mean ± standard deviation (SD).

Table 2 Test condition for tribological tests

Test condition	
Condition	Dry and wet (10 ml DI water)
Motion	Reciprocating sliding (d=10 mm at 1 Hz)
Contact pressure	5 kPa
Normal load	1.5 N
Sliding time	60 s (60 cycles)
Skin care products	• Conotrane • Medihoney • Intrasite • Sudocrem

Results and discussion

Effect of skin care products on friction force traces

Figure 4 shows the friction force of the absorbent pads against skin in both dry and wet conditions. Different skin care products were also applied on the interfaces during sliding contact. Two seconds of data was taken to plot the friction force versus time to show the fluctuation in friction force in detail (stick-slip phenomenon).

For dry skin Figure 4(a), a sliding contact was characterised by a typical square wave frictional trace demonstrating sign of slip or adhesion at the interface. For wet skin, elastic deformation or stick, characterised by a quasi-rectangular Ft vs t curve, at the skin-pad became more prominent as can be seen in Figure 4(b). This will become dominant at lower displacements and higher loads due to elastic compliance of the contact in wet condition with similar observations reported in other related literature [18]. Also, it can be seen that friction force increases towards the end of the stroke in Figure 4(b). This is due to the deformation of skin under compression in front of the pad at the end of stroke where the speed is minimum. Moreover, the greater stability of the friction force was observed in dry condition (Figure 4(a) when compared to the wet condition (Figure 4(b).

For skin care products, evidence of slip was observed in these square wave frictional traces Figure 4(c) and Figure 4(e); characterized by applying skin care products on the interfaces can increase skin hydration [19]. This suggests that the skin properties such as compliance, softness and stiffness can be changed due to hydration of skin [20]. The most obvious change in skin mechanism by hydration is increased compliance and decreased stiffness of interface [20]. The results from this study are in agreement with this statement. It can be seen that the slope of friction force data in Figure 4(a) is less than Figure 4(b) indicating the increase in compliance of wet skin.

On the other hand, it has been reported [21] that presence of skin care products on the skin can form a stiff sheet to increase the stiffness of skin. It is worth noting that the the nature and chemistry of the skin care product itself will influence friction.

Moreover, Figure 4(d) and Figure 4(f) show that adding water on skin care products affected the frictional traces especially for Sudocrem. A deviation away from a traditional square wave friction force was observed for Figure 4(b) when compared to Figure 4(a). This can be explained by extra hydration of the interfaces by adding water. This can potentially disrupt the layer that formed on the surfaces from the skin care products and increase the compliance of the contact.

Dry/ Skin care product	Skin care product+ DI water

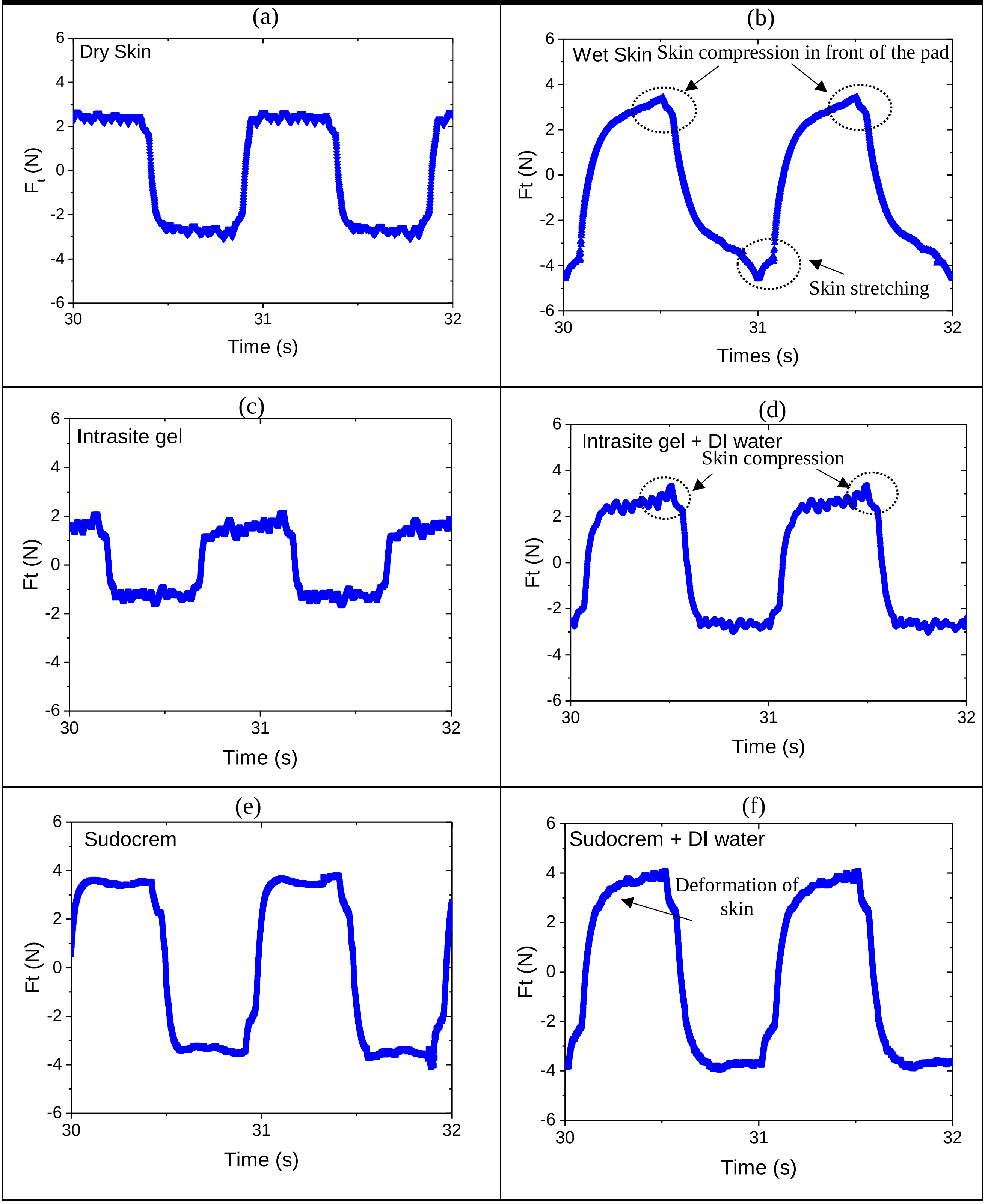

Figure 4 Friction force of the absorbent pad against skin in dry and wet condition during the sliding contact

Figure 5 shows the schematic of deformation of the skin under sliding condition. When the pad slides over the skin the material around the contact area is cyclically deformed and relaxed. During the sliding, the skin is compressed in front of the pad. The effect of the skin compression on friction traces can be seen Figure 4(b). In general, when hydrated (skin care product+water) an increase of deformation prior to the onset of slip can be observed. This is potentially due to the hydration and altered viscoelasticity of the contact.

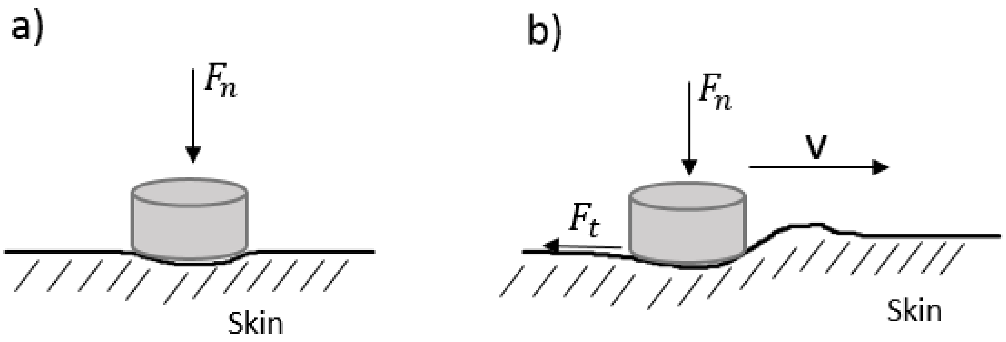

Figure 5 Schematic of skin deformation (a) static conditions (b) under sliding conditions

The friction coefficient was calculated by first calculating the average absolute friction force of the trace and then dividing this by the applied load. Average frictional coefficients (last 20 seconds) between porcine skin and textile applying various skin care products are shown in Figure 6. It was observed that friction increases in wet conditions regardless of skin product care. The increase in friction coefficients of skin with moisture and hydration is in line with other studies [12, 22]. In literature, the friction coefficients of skin have been reported to change between 1.5 and 7 between dry and wet conditions [23]. This large variation in friction values depends on the test method, experimental plan and materials used [22].

In the current study, the highest friction coefficients of skin were found for Sudocrem in both dry and wet conditions. For some other products such as Conotrane there is a slight difference between wet and dry condition. However, Intrasite gel was the only skin care product that showed lower friction coefficient than the skin with no care product even in wet conditions. It has been reported [22] that in dry skin conditions, adhesion caused by surface forces at the skin material interface, as well as deformation of the softer, viscoelastic skin tissue, contribute to the coefficient of friction (CoF). Adhesion mechanism is assumed to be the main contributor to the friction of skin, while deformation is considered to play a minor role [8].

Moreover, it was observed that the friction coefficient was almost constant when no skin-care product was applied. However, the addition of skin care product makes the friction coefficient transient. In the presence of these products, the friction coefficient was low in the beginning and then increased and reached plateau during the test. The spread of skin care product through the skin can act as a barrier to lock moisture in the skin and therefore increase the coefficient of friction. In the beginning of the motion, the coefficient of friction reduces due to the lubricant properties of the skin care products, while later on the coefficient of friction increases due to the increased moisturisation induced by the occlusion [24]. This further raises the questions around the lubricating ability and suitability of some skin care systems and their roles at the skin-textile interface.

Whilst the exact mechanisms of friction for skin are not well understood, there is a general agreement that it is the combination of both adhesion and deformation. Rotaru et al [25] found that wet and dry skin against medical textiles an adhesive mechanisms was prominent; hypothesised as a result of an increase in real contact area due to water uptake. Tomlinson et al [26] present an in depth discussion around the origins of friction between dry and wet finger contacts highlighting two possible mechanisms for increased friction; viscous shearing of liquid bridges as highlighted by Dinc et al [27] and capillary adhesion, as outlined by Persson [28]. Whilst it has not been shown conclusively these mechanisms are at play, there are a number of fundamental system properties common between the two mechanisms. In the current study, the investigation of different skin care products in wet and dry condition demonstrated the complex friction mechanisms of skin and also highlights an important factor neglected in current incontinence related research.

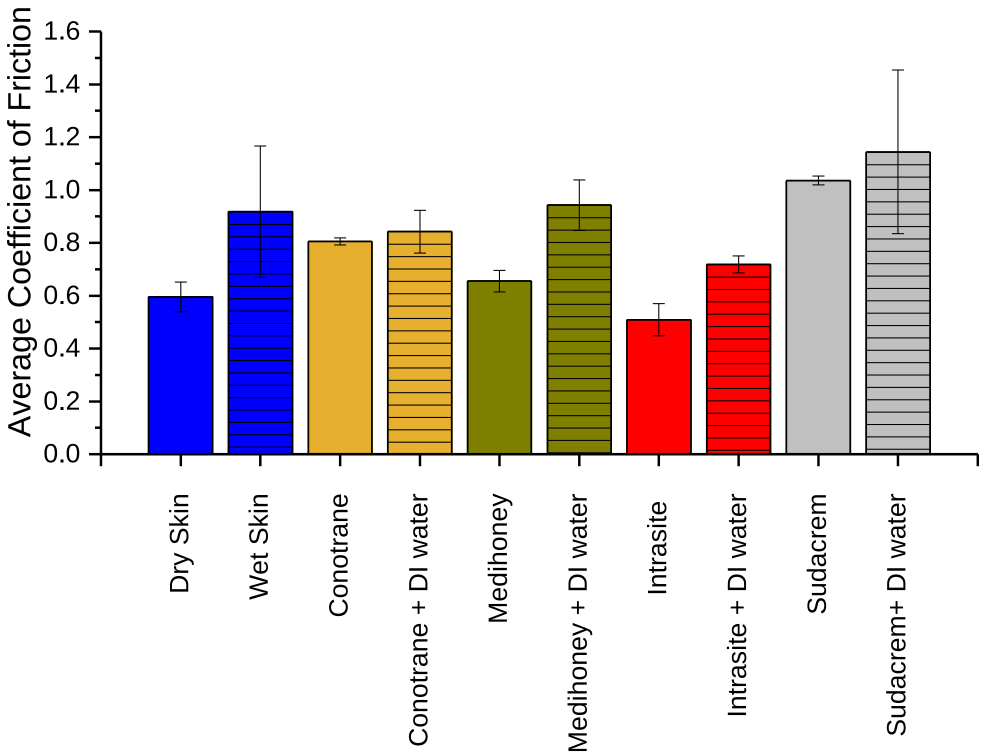

Figure 6 Friction coefficients (mean value ±SD) of the last 20 s of the absorbent pad against different skin care products on the porcine skin, measured on the friction test machine in both dry and wet conditions.

What is particularly interesting from the results presented in this study is the interaction between skin treatment, the effects of moisture and the synergy/antagonism between the two. With the exception of the aqueous-gel based skin treatments (Intrasite), the addition of skin treatment increases the average coefficient of friction when compared to dry skin. Further increments in friction were also observed for some cases with the further addition of water. The mechanisms for this are not clear from the results presented in the current study and are likely to be complex based on the colloidal chemistry and how these interact with skin and absorbent pad. One immediate and usual property that varies between each medicated cream is the rheology.

As discussed above, an increase/decrease in friction is quite credible as a result of the interfacial viscosities of creams within the contact. With products with higher viscosity, higher forces would be required to shear the interfaces resulting in a higher dissipation of shear stress within the contact. Interfacial shear is a significant risk factor in skin heath as highlighted by NICE and a vast amount of evidenced based clinical research [29]. Attention to the mechanisms of frictional dissipation at the interface is therefore important and often neglected in much skin-related tribological research. One particular result of interest is that of the gel-based skin treatments. Considering this has an 80-90% water content, the frictional results demonstrate a decrease in friction even with the addition of water. This may point to a different lubrication mechanism occurring at the interface. It is quite credible that a gel mediated boundary lubrication mechanisms may exist. Further work is required to verify this phenomenon.

In the current study, the addition of water, skin cream as well as a combination of both was seen to affect the slip mechanism at the interface for nominally constant porcine skin type, age and thickness under controlled conditions. However in practice this will be affected by the patient, interface and practice. This study acknowledges that it is important to consider the shear stresses acting on the skin caused by friction, both static and siding, between the skin and skin care products. Whilst sliding, and therefore dynamic friction (i.e. the steady-state resistance to sliding motion) can be seen in most cases, a significant amount of elastic deformation of the contacts can be seen prior to steady-state sliding based on the contact configurations used in this study. As a result no dynamic frictional dissipation at the interface will occur (i.e. sliding of the pad over the skin surface) and the energy dissipated within the contact will likely occur through shear of the pad and skin subsurface. This again will be underpinned by the mechanisms of adhesion outlined above, although analysis of this type helps to identify where and how deformations are occurring at the interface. These type of analysis clarifies why having insight into skin friction may help decrease injuries.

Conclusions

Friction and shear forces at the skin-textile interfaces in the presence of skin care products can cause skin injuries. In the current study, the friction of skin-textile couples, the mechanisms and interactions between contact mechanics, and skin care products were studied. A correlation was found between skin moisture and friction coefficient. It was shown that use of skin care treatments and addition of water/moister can further increase friction. This was explained by change in the mechanisms of slip at the interface through the addition of medicated creams. The sliding nature of the contact was a composite of elastic deformation and sliding depending on the system. Moreover, the results presented in this study demonstrated the importance of understanding the skin-pad interface as a system, with the mechanism of slip varying depending on skin care product. This research highlights that not only the coefficient of friction varies, but also the mechanisms of slip at the interface can be modified further through the addition of medicated creams and water.

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References

1. R. Penzer, S. Ersser. Principles of skin care: a guide for nurses and health care practitioners. Wiley-Blackwell; 2010.
2. P. Dykes, Bradbury S. Incontinence pad absorption and skin barrier creams: a non-patient study. British Journal of Nursing. 2016;25(22). doi: 10.12968/bjon.2016.25.22.1244.
3. M. Morision, K. Wilkie, L.G. Ovington. Chronic wound care: a problem-based learning approach. Edinburgh ; New York : Mosby2004.
4. S. J. Ersser, K. Getliffe, D. Voegeli, et al. A critical review of the inter-relationship between skin vulnerability and urinary incontinence and related nursing intervention. International Journal of Nursing Studies. 2005;42(7):823-835. doi: http://dx.doi.org/10.1016/j.ijnurstu.2004.12.003.
5. J. Hart. Assessment of the incontinence pad blocking potential of Cavilon DBC compared with Sudocrem and Zinc and Castor oil. Nursing Scotland. 2002.
6. L. Fleming, K. Zala, Ousey K. Investigating the absorbency effects of LBF barrier cream - Wounds UK. Wounds UK. 2014;10(2):24-30.
7. L.C. Gerhardt, N. Mattle, G.U. Schrade , et al. Study of skin-fabric interactions of relevance to decubitus: friction and contact-pressure measurements. Skin Research and Technology. 2008;14(1). doi: 10.1111/j.1600-0846.2007.00264.
8. M.J. Adams, B.J. Briscoe, S.A. Johnson. Friction and lubrication of human skin. Tribol Lett. 2007;26(3):239-253. doi: 10.1007/s11249-007-9206-0.
9. M.A. Meyers, P.Y. Chen, A.Yu-Min Lin, et al. Biological materials: structure and mechanical properties. Progress in Materials Science. 2008;53(1):1-206. doi: https://doi.org/10.1016/j.pmatsci.2007.05.002.
10. Z.R. Zhou, Z.M. Jin. Biotribology: recent progresses and future perspectives. Biosurface and Biotribology. 2015;1(1):3-24. doi: https://doi.org/10.1016/j.bsbt.2015.03.001.
11. K.P Wilhelm, P. Elsner, E. Berardesca, et al. Bioengineering of the Skin: Skin Imaging and Analysis. CRC Press; 1997.
12. S. Derler, L.C. Gerhardt. Tribology of skin: review and analysis of experimental results for the friction coefficient of human skin. Tribol Lett. 2012;45(1):1-27. doi: 10.1007/s11249-011-9854-y.

13. IMPRESS netwrok [cited 2018 26 Jan]. Available from: http://impress-network.com/about-incontinence/

14. Medicines [cited 2018 25 Jan]. Available from: https://www.medicines.org.uk/emc/files/pil.5481.pdf

15. A. Simon, K. Traynor, K. Santos, et al. Medical honey for wound care-still the latest resort? Evidence-Based Complementary and Alternative Medicine 2009;6(2):165-173. doi: 10.1093/ecam/nem175. PubMed PMID: PMC2686636.

16. SMTL dressings datacard [cited 2018 25 Jan]. Available from: http://www.dressings.org/Dressings/intrasit.gel.html

17. Sudocream [cited 2018 25 Jan]. Available from: http://www.boots.com/sudocrem-antiseptic-healing-cream-125g-10006321

18. E. Van Der Heide, X. Zeng, M.A. Masen. Skin tribology: science friction? Friction. 2013;1(2):130-142. doi: 10.1007/s40544-013-0015-1.

19. N. Domoto, T. Koriyama, B.S. Chu, et al. Evaluation of the efficacy of orange roughy (Hoplostetbus atlanticus) oil in subjects with dry skin. International Journal of Cosmetic Science. 2012;34(4):322-327. doi: 10.1111/j.1468-2494.2012.00719.x.

20. J. de Rigal, J.L. Leveque. In vivo measurement of the stratum corneum elasticity. Bioengineering and the Skin. 1985;1(1):13-23.

21. S. Guest, F. McGlone, A. Hopkinson, et al. Perceptual and sensory-functional consequences of skin care products. Journal of Cosmetics, Dermatological Sciences and Applications. 2013;3(1):13. doi: 10.4236/jcdsa.2013.31A010.

22. K.P. Wilhelm, P. Elsner, E. Berardesca, et al. Bioengineering of the skin: skin imaging & analysis. 2006.

23. R.K. Sivamani, G.C. Wu, N.V. Gitis, et al. Tribological testing of skin products: gender, age, and ethnicity on the volar forearm. 2003;9(4):299-305.

24. S. Nacht, J.A. Close, D. Yeung, et al. Skin friction coefficient: changes induced by skin hydration and emollient application and correlation with perceived skin feel. Journal of the Society of Cosmetic Chemists. 1981;32(2):55-65.

25. G. M. Rotaru, D. Pille, F. K. Lehmeier, et al. Friction between human skin and medical textiles for decubitus prevention. Tribology International. 2013;65:91-96. doi: http://dx.doi.org/10.1016/j.triboint.2013.02.005.

26. S. E. Tomlinson, R. Lewis, X. Liu, et al. Understanding the friction mechanisms between the human finger and flat contacting surfaces in moist conditions. Tribol Lett. 2011;41(1):283-294. doi: 10.1007/s11249-010-9709-y.

27. O. S. Dinç, C. M. Ettles, S. J. Calabrese, et al. Some parameters affecting tactile friction. Journal of Tribology. 1991;113(3):512-517. doi: 10.1115/1.2920653.

28. B. N. J. Persson. Capillary adhesion between elastic solids with randomly rough surfaces. Journal of Physics: Condensed Matter. 2008;20(31).

29. D. Beeckman. A decade of research on incontinence-associated dermatitis (IAD): evidence, knowledge gaps and next steps. Journal of Tissue Viability. 2017;26(1):47-56. doi: https://doi.org/10.1016/j.jtv.2016.02.004.