



The influence of two alcohol-based hand rubs on skin barrier function of black African female students

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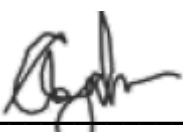
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Graduation: June 2025

DECLARATION

I, CA Uren hereby declare that the dissertation entitled '*The influence of two alcohol-based hand rubs on skin barrier function of black African female students*' is my work, and complies with the code of academic integrity, as well as other relevant policies, procedures, rules, and regulations of the North-West University

- that all the sources quoted have been acknowledged by using references, and
- that this dissertation has not been submitted before to any institution by me or any other person in fulfilment of requirements for the attainment of any qualification



Signature

27 November 2024
Date

DEDICATION

I dedicate this work to all the study participants. Your participation made the study possible and contributed to the body of knowledge on the subject matter.

I also dedicate this work to my family, who have been my source of strength and love throughout the journey.

PREFACE

This dissertation is structured into four chapters and follows the APA referencing style, as outlined in the Publication Manual of the American Psychological Association (7th edition). The layout is as follows:

Chapter 1 provides the background, literature review, problem statement, aim, and objectives.

Chapter 2 outlines the study design, methods, and procedures.

Chapter 3 presents manuscript one, titled: The influence of two alcohol-based hand rubs on the skin barrier function of black African female students

Chapter 4 serves as the concluding chapter, summarizing the main findings, conclusions, and recommendations.

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ABSTRACT

Effective hand hygiene remains paramount in infection and prevention programmes. Healthcare workers have an increased prevalence of skin irritation owing to frequent hand hygiene practices. Alcohol-based hand rubs (ABHRs) are often recommended for hand hygiene practices due to their effectiveness, practicality, and safety profile. Research comparing the effects of detergent soaps and ABHRs on skin conditions is abundant; however, it is limited to Caucasian populations. Current research strongly favours disinfection by ABHRs over detergent soaps as they are better tolerated. **Aim:** This study aims to assess and compare the acute effects of ethanol-based and isopropyl-based hand rubs on skin barrier function in a black African female population, a demographic that is often underrepresented in skincare research. **Method:** Thirty female African students with Fitzpatrick skin type V or VI, not suffering from any pre-existing skin pathology in the age range of 20-30 years, participated in the study. Two ABHR interventions were applied to randomised sampling sites on the volar forearm of the non-dominant arm at six measurement intervals over eight hours. Skin barrier function was assessed by standardised measurements such as transepidermal water loss (TEWL), stratum corneum hydration (SCH), and skin surface pH (SS-pH). **Results:** None of the ABHR interventions caused significant changes in TEWL, while SCH levels improved, particularly with ABHR1, indicating superior moisturising properties. Additionally, both ABHRs reduced SS-pH to a slightly acidic level, which is beneficial for skin barrier protection and repair. **Conclusion:** Both ABHRs (ethanol- and isopropyl-based) were well tolerated by the skin and did not disrupt the skin barrier of an African female population when applied acutely over eight hours.

Key Words: Alcohol-based hand rubs; healthcare workers; skin barrier function; transepidermal water loss; stratum corneum hydration, skin surface pH

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CHAPTER 1: INTRODUCTION

1.1 Overview

Since the COVID-19 pandemic highlighted the importance of hand hygiene practices, alcohol-based hand rubs have become essential for infection control due to their proven effectiveness in reducing microbial load (Hui-Beckman et al., 2022). However, concerns were raised regarding the potential negative effects of frequent ABHR use on skin barrier function. Studies have linked the consistent application of ABHRs to increased transepidermal water loss (TEWL), decreased stratum corneum hydration (SCH), and changes in apparent skin surface pH (SS-pH). These factors are key indicators of skin barrier health (Plum et al., 2020; Hui-Beckman et al., 2022).

Healthcare workers (HCWs) such as nurses are required to adhere to strict hand hygiene practises involving conventional hand washing or disinfection by alcohol-based hand rubs (ABHRs) to prevent the spread of pathogens throughout the healthcare setting (Pittet et al., 2000; Khan et al., 2017). Healthcare workers have a higher prevalence of skin irritation owing to frequent hand hygiene practices. Irritated and damaged skin not only causes discomfort and work absenteeism but also increases the risk of spreading infection as HCWs are less likely to adhere to hand hygiene protocols (Larson et al., 2006).

Despite hospital infection control programmes' guidelines, hand hygiene compliance remains relatively low. An important element in improving hand hygiene practice is conventional washing methods, which use mild soap and water, and disinfection by ABHRs. Alcohol-based hand rubs are preferred preparations for hand hygiene in health care settings as they require less time to clean hands, are proven to be more microbiologically effective, and are less irritating to the skin in comparison to traditional hand washing with soap and water (Trampuz and Widmer, 2004). ABHRs vary greatly in terms of their formulations, drying characteristics, consistency, cost, scent, and other features. Some formulations of ABHRs are tolerable to almost all HCWs, while others are not (CDC, 2002).

1.2 Skin barrier function parameters

There are several methods, both invasive and non-invasive, to assess skin barrier function. The measurement of transepidermal water loss (TEWL) is the most commonly used in clinical studies. This measurement is often accompanied by other assessments of biophysical parameters, including stratum corneum (SC) hydration, skin surface pH, and tape stripping. Less commonly used techniques, such as Raman spectroscopy, can also evaluate skin barrier function (Kleesz et al., 2012; Antonov et al., 2016). Kezic and Nielsen (2009) found that a compromised barrier function increases the absorption of xenobiotic substances through the skin.

Measuring transepidermal water loss (TEWL) has evolved from a method originally used to assess infant dehydration rates to a key indicator of skin barrier integrity and function. TEWL is considered one of the most reliable and direct methods for evaluating skin barrier function, as it measures the natural water loss through the stratum corneum (SC). This process is independent of perspiration and does not rely on sweat gland activity or location (Pirrot and Falson, 2004; Löffler and Kampf, 2008).

Normal TEWL values in a healthy Caucasian population range from 10 g/m²/h to 13 g/m²/h when measured on the ventral forearm and dorsal hand (Kleesz et al., 2012). Higher TEWL values indicate impaired barrier function, with the baseline TEWL of psoriatic skin being approximately 2.5 times higher than that of normal skin (Janssens et al., 2012; Thorkar and Hamde, 2015).

Stratum corneum (SC) hydration is assessed indirectly through electrical properties such as conductance, impedance, or capacitance of the skin, all of which depend on the water content of the SC (Du Plessis et al., 2013). For healthy individuals, the water content of the stratum corneum is approximately 30 ± 5%. SC hydration is a vital factor that affects SC permeability, enzymatic activity, the mechanical properties of the skin, and its superficial appearance (Denda et al., 1998; Harding et al., 2000; Caspers et al., 2001). Additionally, there is often an inverse relationship between SC hydration and transepidermal water loss (TEWL). Typically, high TEWL values are associated with low hydration levels, both of which indicate impaired barrier function (Proksch et al., 2008).

A glass planar electrode connected to a voltmeter is utilised for potentiometric measurements of skin surface pH. The acidic environment of the skin surface is crucial for stratum corneum (SC) homeostasis and the maintenance of microbial flora (Stefaniak et al., 2013). According to existing literature, normal skin pH values range from 4.0 to 7.0. Lower skin surface pH values, specifically between 4.5 and 5.6, are deemed indicative of healthy and intact skin, while higher pH values are associated with increased transepidermal water loss (TEWL) (Lambers et al., 2006; Darlenski et al., 2009).

Skin condition is generally characterised by a combination of surface texture, colour, and physiological properties, including SC hydration, surface pH, and sebum content. Adequate SC hydration is essential for achieving a smooth and soft appearance. The sebaceous glands produce sebum, which, along with other epidermal lipids, helps maintain skin hydration by minimising fluid loss. Moreover, cutaneous lipids and amino acids play a role in contributing to surface acidity; a low pH level is instrumental in providing protection against pathogens (Pathak, 1982; McCallion and Li Wan Po, 1993; Dubertret, 2000).

1.3 Problem statement

The influence of ABHRs on skin barrier parameters is a critical research area, especially given the heightened emphasis on hand hygiene since the COVID-19 pandemic. While ABHRs are highly regarded for their ability to lower microbial presence, considerable research has been conducted into how they affect skin barrier function. However, there remains a need to understand the effects of ABHRs on the skin barrier function of black African females, a demographic often underrepresented in dermatological research

The study investigated the impact of two ABHRs on skin barrier function, specifically TEWL, SCH, and SS-pH, over eight hours in an apparently healthy African female student population.

The study will include two ABHR interventions, one used in a public healthcare facility and the other in a private healthcare facility. Therefore, if one type of ABHR is found to be better tolerated by the skin, it could be motivated for use in the other respective facility

1.4 Research Aim

The general aim of the study was:

To establish and compare the acute (8-hour) influence of two types of alcohol-based hand rubs on the skin barrier function of black African female students, as determined by TEWL, SC hydration, and skin surface pH.

1.5 Research Objectives

The research objectives were:

- 1) To establish the influence of two types of ABHRs on the skin barrier function of a black African female population over eight hours as determined by TEWL, SCH, and SS-pH.
- 2) To compare the effects of ethanol-based and isopropyl-based hand rub formulations on the skin barrier function, specifically TEWL, SCH, and SS-pH.

1.6 Hypotheses

(i) Published studies on the effects of alcohol-based hand rubs (ABHRs) on skin barrier function have reported increased transepidermal water loss (TEWL), decreased stratum corneum hydration (SCH) and increased skin surface pH (SS-pH) , suggesting potential impairment of skin barrier integrity. Based on these findings, it is hypothesised that both ABHR1 and ABHR2 will significantly affect the skin barrier parameters (Increased TEWL, decreased SCH and increased SS-pH).

(ii) Comparative studies of alcohol-based hand rubs have shown variability in their effects on skin function barrier parameters. Based on these findings, it is hypothesised that ABHR1 will have a more pronounced negative impact on TEWL, SCH, and SS-pH compared to ABHR2.

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LITERATURE REVIEW

2.1 Background

The skin serves as the first line of defence against environmental threats and pathogens (Proksch et al., 2008). In healthcare settings, maintaining skin integrity is crucial, particularly for healthcare workers (HCWs) who frequently use alcohol-based hand rubs (ABHRs) as part of their hand hygiene protocols (WHO, 2009). The COVID-19 pandemic highlighted the importance of hand hygiene practices, making alcohol-based hand rubs essential for infection control due to their proven effectiveness in reducing the microbial load (Hui-Beckman et al., 2022).

However, concerns have arisen regarding the potential negative effects of frequent ABHR use on skin barrier function. Studies have linked the consistent application of ABHRs to increased transepidermal water loss (TEWL), decreased stratum corneum hydration (SCH), and changes in apparent skin surface pH (SS-pH). These factors are key indicators of skin barrier health (Plum et al., 2020; Hui-Beckman et al., 2022).

Understanding how ABHRs affect skin barrier function is crucial for developing effective hand hygiene protocols that balance infection control with skin health considerations. Disruption of the skin barrier is the first step in developing atopic dermatitis or other skin conditions (Kim and Leung, 2018; Rosmarwati et al., 2022).

Alcohol-based hand rubs (ABHRs) are preferred over traditional handwashing due to their superior ability to reduce microbes and their convenience, especially when they contain emollients that help maintain skin hydration (Kampf and Kramer, 2004; WHO, 2009). While ABHRs are generally less harsh on the skin than soap and water, their effects on skin barrier function including TEWL, SCH, SS-p) are not completely understood (Plum et al., 2020; Hui-Beckman et al., 2022). Most existing research, which primarily focused on the Caucasian population, highlights the necessity for more inclusive studies. Such studies are essential for developing hand hygiene protocols that effectively balance efficacy with skin health (Tarka et al., 2019; Rosmarwati et al., 2022).

This chapter will explore the fundamental anatomy, physiology, and pathophysiology of the skin, focusing on the effects of various factors on skin health. It will also examine the functions and applications of ABHRs commonly used in healthcare settings. Additionally, the chapter will review existing literature on ABHRs and discuss the environmental, exogenous, and endogenous factors that influence important skin barrier parameters, including TEWL, SCH and SS-pH.

2.2) Anatomy and Physiology of the Skin

The skin is the largest organ in the human body and is composed of three primary layers: the epidermis, the dermis, and the subcutaneous tissue. The outermost layer, the epidermis, features the stratum corneum. The stratum corneum is composed of corneocytes embedded in a continuous lipid membrane, which plays a critical role in maintaining skin hydration and preventing TEWL (Jung et al., 2019).

The stratum corneum, made up of dead keratinised cells, serves as a crucial protective barrier that prevents water loss and shields the body from environmental threats (Makhakhe, 2023). This outermost layer is essential for maintaining skin integrity, allowing activities such as swimming or showering without damaging the underlying cells. It also protects against the entry of pathogens and harmful chemicals, safeguarding the internal environment from numerous transient bacteria species present on the skin's surface (McGrath et al., 2004; Scanlon et al., 2011). Through a natural process called desquamation, dead cells are shed, helping remove microorganisms, while fatty acids in sebum inhibit microbial growth (McGrath et al., 2004; Scanlon et al., 2011).

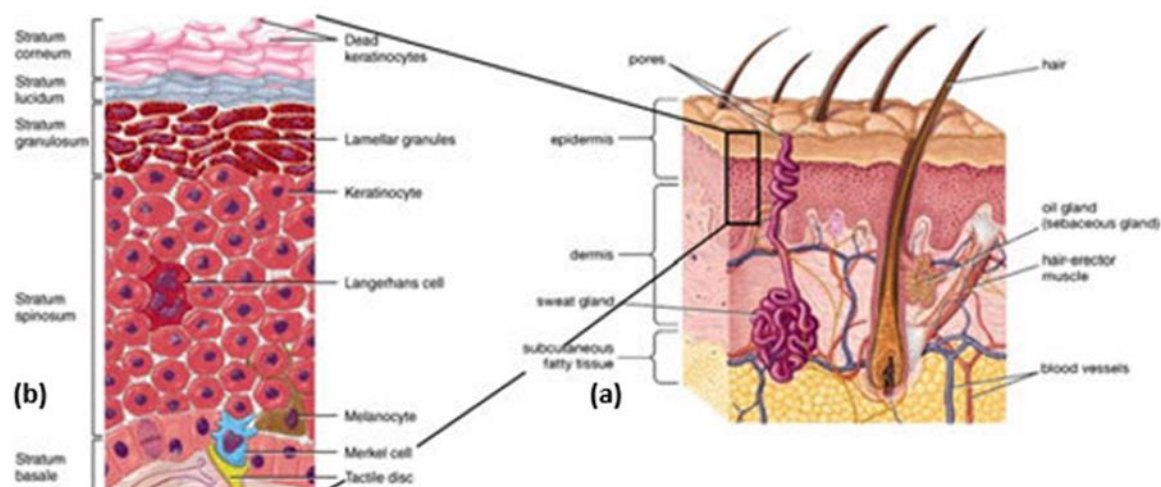


Figure 1: Schematic illustration of human skin layers. (a) Three main layers: Epidermis, dermis, and subcutaneous fat (hypodermis). (b) A closer look (excerpt from figure (a)) at the five substratum-layers of the epidermis: stratum corneum, stratum lucidum, stratum granulosum, stratum spinosum and stratum basale (Betzalet et al., 2017).

2.3) Skin barrier function

The skin's barrier function is primarily due to the stratum corneum, which plays a crucial role in regulating TEWL and SCH and preserving the skin's acid mantle (SS-pH). A healthy skin barrier is vital for overall skin health, as it prevents dehydration and protects against irritants and pathogens (Hui-Beckman et al., 2022). When this barrier is disrupted, it can lead to conditions such as dermatitis and a greater vulnerability to infections. The three most used biophysical parameters to quantify skin barrier function will be discussed in short:

2.3.1) Transepidermal water loss (TEWL)

TEWL is the most commonly used objective test for assessing the skin's barrier function, especially in individuals with skin conditions like atopic dermatitis, which is associated with impaired skin barrier function (Akdeniz et al., 2018; Pal, 2023). TEWL is the quantity of water vapour which passively diffuses from the stratum corneum to the surrounding environment, often expressed in $\text{g/m}^2/\text{h}$. Water loss is part of normal skin metabolism; due to a water vapour pressure gradient on both sides of the skin, TEWL is directly proportional to the skin's hydration status (Campbell, 2004; Maibach and Honari, 2014). Healthy, intact skin restricts excessive water loss; conversely, once the skin barrier is impaired, the rate of water loss significantly increases, as commonly observed in atopic skin. TEWL measurements assess the skin condition during various exposures and allow for the early detection of barrier disruption even before visible damage. The average water loss in humans in the form of TEWL is approximately 300 to 400 millilitres per day. It is influenced by various endogenous and exogenous factors like humidity, temperature, age, anatomical location, circadian rhythm, and skin health, to mention a few (Braun-Falco and Korting, 1986; Du Plessis et al., 2013a; Maibach and Honari, 2014; Engebretsen et al., 2016). Multiple techniques exist for measuring TEWL; specialised instruments are designed as either open chamber- or closed chamber- or, more recently, condensed chamber -devices. Open chamber devices are open to the external atmosphere and allow for the continuous assessment of TEWL without affecting the microclimate of the measurement site; caution is required to control external influences. In contrast, closed chamber devices are enclosed and are not influenced by the surrounding atmosphere. However, they accumulate water vapour, which inhibits continuous measurement, while condensed chambers mitigate this issue by inhibiting vapour build-up (Stefaniak et al., 2013; Alexander et al., 2018).

TEWL measurements are valuable in determining barrier function integrity with higher values, often indicative of an impaired skin barrier. Differences in TEWL estimates for different instruments are reported to be minimal. Various guidelines have been published to control factors influencing TEWL and to standardise experimental procedures, which is essential for proper

interpretation and comparison of results (Kottner et al., 2013; Du Plessis et al., 2013a; van Rensburg et al., 2019).

2.3.2) Skin Surface pH (SS-pH)

pH is defined as the negative logarithm of the molar concentration of Hydrogen ions (Lewis and Bamforth, 2007). It is a figure expressing the acidity-alkalinity ratio of a solution on a logarithmic scale that ranges from 0 (strongly acidic) to 14 (strongly alkaline), with 7 being neutral. Various skin barrier functions, such as cutaneous barrier repair and antimicrobial defence, are related to the acidic characteristics of the skin. Furthermore, SS-pH is known to affect the dissolution and partitioning of chemicals with which it comes into contact, thereby influencing its exposure profile, this increases the risk of skin disease pathology (Stefaniak et al., 2013). SS-pH measurements are essential to understanding skin health and barrier function. Contradictory evidence exists regarding SS-pH values across different races and sexes, more recent literature reports normal SS-pH to be in the range of 4.1 to 5.8 across most anatomical areas (Segger et al., 2008, Jung et al., 2012, Young et al., 2019). Atopic dermatitis often presents elevated SS-pH values, which fall in the neutral to alkaline range. Upon experimental disruption of the skin barrier, SS-pH values generally increase and return to normal ranges after barrier repair has occurred. A lower pH commonly corresponds with decreased TEWL and higher SCH values in healthy populations (Lambers et al., 2006; Darlenski et al., 2009; Proksch, 2018).

Another key factor closely linked to SS-pH is the skin's microbiome which plays an integral role in maintaining skin health and immune function, influencing various dermatological conditions. The skin microbiome is composed of a wide variety of microorganisms, with its composition influenced by skin physiology which is affected by several intrinsic and extrinsic factors (Boxberger et al., 2021, Gilaberte et al., 2024). Dysbiosis, an imbalance or disruption of the resident microbiome can further compromise the skin barrier, increasing the susceptibility to infections, inflammatory skin conditions and impaired barrier repair (Fyhrquist et al., 2023, Hyun-Ji and Miri, 2022). Furthermore, the immune system also plays a vital role in the function of the skin barrier. Immune cells such as Langerhans cells, mast cells and T cells detect and respond to microbial threats. Overzealous hand hygiene practices may negatively affect the skin microbiome and its immune function (Rocha et al., 2009, Nguyen and Soulika, 2019). However, the frequent occupational use of ABHRs particularly ethanol-based solutions are reported to not adversely affect the composition of the hand microbiome (Mukherjee et al., 2018, Kramer et al., 2024).

Several instrumentations with distinctive measurement principles exist to measure SS-pH. SS-pH is usually obtained by non-invasive measurement techniques, most commonly being pH probes or electrodes. These devices use a glass electrode that reacts to the hydrogen ion concentration present on the skin surface (Du Plessis et al., 2018). The planar glass electrode method produces fast and reproducible results while avoiding occlusion effects. The method is based on the difference in potential generated on each side of a thin glass slide partitioning two solutions; their variance linearly links them in Hydrogen ion concentration (Agache and Humbert, 2004; Darlenski et al., 2009).

2.3.3) Stratum Corneum Hydration (SCH)

SCH refers to the water content in the uppermost skin layer, more commonly known as the stratum corneum. Hydration is essential to skin health and significantly influences its physical and mechanical properties (Manfredini et al., 2013; Du Plessis et al., 2013; Mojumdar et al., 2017). The integrity of the skin barrier prevents the excessive loss of water from the internal environment and maintains the optimal hydration of the epidermis (O'goshi and Serup, 2005). Therefore, the hydration status of the SC provides information on the current condition of the skin's barrier function. Skin hydration represents the water content of the epidermis and dermis. As water content increases in the SC, it causes a change in its dielectric properties (Denzinger et al., 2020).

The water content of the stratum corneum is expressed in arbitrary units (a.u). For healthy individuals, a sufficiently hydrated SCH value of the mid-ventral forearm is 45 a.u (constin et al., 2014a). SCH is a significant factor that influences SC permeability, enzymatic activity in the SC, the mechanical properties of the skin, and its superficial appearance (Sato et al., 1998; Morris et al., 2000; Caspers et al., 2001). Furthermore, an inverse relationship between SCH and TEWL often exists. Low hydration levels ordinarily accompany high TEWL values, both being indicative of an impaired barrier function (Proksch et al., 2008).

The water content of the stratum corneum (SCH) is measured in arbitrary units (a.u.). A sufficiently hydrated SCH value for the mid-ventral forearm is 45 a.u in healthy individuals. SCH plays a significant role in determining the permeability of the stratum corneum, the enzymatic activity within it, the skin's mechanical properties, and its overall appearance (Constantin et al., 2014; Mayrovitz, 2023).

SC hydration measurements are influenced by particular variables such as ethnicity/race, anatomic site and even gender (Man et al., 2009; Darlenski and Fluhr, 2012). The SCH state is also affected by ambient relative humidity as the stratum corneum is exposed to the atmosphere (Proksch et al., 2008).

Various non-invasive methods exist to determine SCH, most of which do so indirectly. Measurement principles are based on electrical properties such as conductance, impedance, or capacitance of the skin, all dependent on the water content of the SC (Du Plessis et al., 2013).

2.4) Factors Influencing Skin Barrier Function

Skin barrier function is influenced by several factors, such as race, age, sex/gender, the anatomical site of the skin, the level of perspiration, environmental temperature, humidity, circadian rhythm, individual differences like skin type, and underlying dermatological conditions (Du Plessis et al., 2013; Dąbrowska, 2018; Rivers and Kauffman, 2021).

2.5) Endogenous factors

2.5.1) Age

TEWL (transepidermal water loss) estimates are generally considered independent of the age of the working-age population. However, some studies indicate that TEWL levels may be slightly lower in individuals aged 65 and older compared to middle-aged individuals. Although TEWL tends to decrease slowly but steadily with age, the published data lacks a clear consensus on this trend, despite several studies suggesting that TEWL decreases as people get older. (Machado et al., 2010; Du Plessis et al., 2013; Kottner et al., 2013). On the other hand, some studies indicate that intrinsic ageing results in both structural and functional changes in the skin. These changes include a decrease in skin integrity due to the natural ageing of cells and modifications in the extracellular matrix (Lee et al., 2021). As a result, the skin becomes more vulnerable to injuries and external stressors, especially in older adults (Farage et al., 2013).

As individuals age, there is a notable inverse relationship between SCH and age. This decline in SCH is linked to a decline in natural moisturizing factors (NMF), such as ceramides and filaggrin, within the stratum corneum. Consequently, the skin's water content decreases over time (Cho et al., 2019; Boireau-Adamezyk et al., 2021). Additionally, aging skin experiences an increase in SS-pH, which correlates with a compromised skin barrier. Factors contributing to this elevated SS-pH include reduced sebum production and decreased SCH. Collectively, these changes underscore the importance of maintaining NMF levels and managing the respective biophysical parameters to preserve skin barrier function as we age (Jürgen et al., 2011; Huang et al., 2024).

2.5.2) Race

Racial differences in skin physiology, including variations in pigmentation, hydration levels, and skin barrier function, significantly impact how the skin reacts to external factors (Muizzuddin et al., 2010). Although the thickness of the stratum corneum (SC) appears consistent across different racial groups, individuals with darker skin often show higher levels of TEWL. However, findings regarding SC hydration remain inconclusive (Wesley & Maibach, 2003; Darlenski et al., 2009; Du Plessis et al., 2013).

Skin surface pH generally exhibits minimal variation under normal conditions; however, changes observed after applying adhesive tape suggest that factors such as sebum production, sweat gland activity, and external conditions can influence it (Wesley and Maibach, 2003). Recent studies have highlighted the compact structure of the SC and the unique barrier properties of Black skin, underscoring the importance of personalised skincare approaches (Adegbenro and Taylor, 2013).

2.5.3) Gender

Gender has a significant impact on skin barrier function, particularly with estrogen playing a crucial role in maintaining skin integrity in women. The decline in estrogen levels during menopause accelerates skin ageing and weakens the skin barrier, leading to a more pronounced effect on women compared to similarly aged men (Bravo et al., 2024). Two major reviews conducted by Drau Plessis et al. (2013) and Rahrovan (2018) examined the biophysical properties of skin between males and females. These studies found insufficient evidence to conclude that gender affects TEWL and skin hydration (Du Plessis et al., 2013; Rahrovan et al., 2018). Similar results were reported for other parameters of skin barrier function. It is noteworthy that sebum content is higher in men, as sebum production is significantly influenced by (testosterone) sex hormones (Rahrovan et al., 2018).

The influence of gender on SS-pH remains a topic of considerable debate, with studies reporting mixed and inconclusive results (Du Plessis et al., 2018). Some research suggests that males have a lower SS-pH than females, attributed to physiological factors such as sebum production and sweat rates. Conversely, other studies indicate that females exhibit lower SS-pH levels, with variability in findings depending on anatomical location (Ehlers et al., 2001; Luebberding et al., 2013).

2.6) Exogenous factors

External factors, such as lifestyle choices and environmental conditions, significantly impact the skin barrier.

2.6.1) Smoking

The impact of smoking on TEWL remains unclear due to a lack of sufficient information in the literature. Muizzuddin (1997) compared the TEWL of active smokers to that of non-smokers and found no significant difference between the two groups. Similarly, Xin et al. (2016) assessed the biophysical properties of the skin barrier in light and moderate smokers, reporting inconsistent results. They noted no significant difference in TEWL between the groups and no correlation between basal TEWL and the number of years an individual had smoked (Muizzuddin et al., 1997; Xin et al., 2016).

Despite these inconclusive findings on TEWL, it is well-established that smoking accelerates skin ageing by inducing oxidative stress. This oxidative stress can impair skin structure and barrier function, leading to features of extrinsic ageing (Rauscher et al., 2024). However, further research is needed to determine whether smoking significantly affects skin surface pH (SS-pH) or stratum corneum hydration (SCH).

2.6.2) Alcohol

Grain alcohol, particularly ethanol, is linked to various skin diseases. Research has shown that ethanol consumption increases TEWL (Jacobi et al., 2005). A study conducted by Jang et al. (2010) found that TEWL, skin hydration, and skin pH significantly rose within 30 minutes after alcohol consumption. At the same time, body temperature and sebum content were observed to decrease. The study concluded that alcohol consumption affects thermoregulation, skin barrier function, and SS-pH, although it did not provide specific details on the changes in pH. Generally, alcohol consumption tends to result in a more alkaline skin surface pH, which can disrupt the skin's acid mantle and impair its barrier function. Excessive alcohol consumption also causes oxidative damage, contributing to premature skin ageing and decreased barrier efficiency (Knaggs and Lephart, 2023).

2.6.3) Caffeine

Brandner et al. (2006) conducted a study in which a caffeine solution was topically applied to one forearm of male and female volunteers, while the opposite forearm served as the control. The investigation lasted seven days, during which TEWL was recorded before and after the intervention. Baseline TEWL did not significantly differ between male and female participants. However, the application of caffeine resulted in a significant reduction in TEWL in male skin compared to female skin. This suggests that caffeine positively affects skin barrier function in males (Brandner et al., 2006).

While the direct effects of caffeine on skin barrier function are not extensively studied, some evidence indicates that high caffeine intake may be associated with increased skin sensitivity and dryness, potentially impacting the skin's barrier properties (Herman and Herman, 2012). However, there is limited information regarding the influence of caffeine on skin surface pH (SS-pH) or stratum corneum hydration (SCH) (Draelos, 2018).

2.7) Environmental factors

Environmental factors, such as seasonal changes, ambient temperature, and relative humidity, can also influence the skin barrier.

2.7.1) Season

Seasonal changes are closely linked to climate variations, including shifts in temperature, air quality, and humidity. These climatic changes can significantly impact the skin's barrier function and influence TEWL (Hui-Beckman et al., 2023). Numerous studies have examined the effects of seasonal fluctuations on skin barrier function, with most findings indicating that TEWL values increase significantly in winter compared to summer (Green et al., 2022, Camilion et al., 2022).

While TEWL is frequently emphasized, other parameters, such as SCH, are also affected by seasonal variations. Winter often brings lower humidity levels, which can adversely affect SCH, leading to decreased skin hydration and compromised barrier function (Hui-Beckman et al., 2023). The dry, cold weather and low humidity during winter can worsen these effects, making the skin more vulnerable to damage and irritation.

2.7.2) Ambient temperature

The skin is a crucial thermoregulatory organ that helps maintain a constant body temperature. When environmental conditions, such as high temperatures, occur, blood flow to the skin increases through a process called vasodilation, and sweat glands become active. Sweating aids in heat loss, and while it may cause a temporary increase in stratum corneum hydration (SCH) due to moisture accumulating on the skin's surface, the overall effect on SCH can vary.

Increased sweating can also result in elevated TEWL as moisture evaporates from the skin, which may lead to a net loss of hydration in the stratum corneum (Serup et al., 2006, Rawlings and Harding, 2004). It is important to note that TEWL is not solely dependent on sweating; it is influenced by various factors, including environmental humidity and skin barrier integrity (Serup et al., 2006). Extremes in temperature, whether hot or cold, can stress the skin barrier, compromising its function and increasing susceptibility to dehydration and irritation (Rawlings and Harding, 2004).

2.7.3) Relative humidity

The effects of high relative humidity on skin barrier function are comparable to those of high temperature. When humidity levels rise, sweat on the skin surface cannot evaporate effectively, leading to increased hydration of the stratum corneum. However, elevated humidity can also heighten the permeability of the stratum corneum due to the greater water content, which may result in increased TEWL (Warner et al., 2003, Sreekantaswamy et al., 2024).

In contrast, low-humidity environments accelerate water loss, which negatively impacts the integrity of the skin barrier, leading to an increase in TEWL (Rauscher et al., 2024). Additionally, low humidity can alter SS-pH, potentially creating a more alkaline environment that compromises the skin's acid mantle and its protective functions.

2.8) Occupational skin diseases

Skin disorders resulting from workplace exposure are common, with occupational skin diseases (OSDs) ranking as the second most prevalent type of occupational disease globally (Flyvholm et al., 2005; Bourke, 2006; Charles et al., 2009). In several European countries, OSDs account for up to 40% of all reported occupational diseases, with contact dermatitis, skin cancer, and contact urticaria being the most frequent types (Alfonso et al., 2017). These conditions lead to significant morbidity, loss of workdays, and financial consequences due to changes in job roles or career paths (Murphy, 2007). OSDs are often associated with exposure to hazardous agents in the workplace, whether physical, chemical, or biological, which play a crucial role in the

development of these diseases (Srinivas and Sethy, 2023). Higher prevalence rates are noted among individuals in occupations such as construction, painting, laundry, engineering, hairdressing, hospitality, printing, agriculture, and healthcare, where exposure to skin hazards is common (Rai et al., 2021, Lurati, 2015).

Healthcare workers (HCWs) are especially vulnerable to OSDs due to regular exposure to detergents, cleaning agents, frequent handwashing (wet work), and chemicals found in latex products, disinfectants, and preservatives (Rai et al., 2021; Campion, 2015). The growing concern about frequent hand hygiene practices, including the use of alcohol-based hand rubs (ABHRs), is significant among HCWs, as these practices can lead to irritant contact dermatitis (ICD) and other skin conditions (Rosmarwati et al., 2022). Understanding the prevalence and impact of these conditions is essential for developing effective interventions to protect the skin health of healthcare workers.

Among OSDs, occupational contact dermatitis is the most prevalent, accounting for 70–95% of all cases worldwide (Sasseville, 2008; Cahill et al., 2016). It is primarily divided into irritant contact dermatitis (ICD), which accounts for 80% of cases, and allergic contact dermatitis (ACD). Both forms typically present as non-contagious inflammatory reactions on exposed areas, particularly the hands. ACD, although less common, can vary from mild localised symptoms to severe systemic reactions (Larson et al., 2006; Sasseville, 2008).

Irritant Contact Dermatitis (ICD) is marked by localised inflammation resulting from a single or repeated exposure to irritants such as chemicals (e.g., detergents, disinfectants) or physical factors like cold temperatures or mechanical friction (Diepgen, 2003). Acute ICD is caused by exposure to strong irritants, whereas chronic ICD arises from repeated exposure to milder irritants, impairing the skin barrier's ability to fully recover (Ale & Maibach, 2014).

Allergic Contact Dermatitis (ACD), which accounts for 20% of occupational dermatitis cases, results from a cell-mediated immune response. It includes a sensitization phase during which initial exposure to an allergen produces no visible reaction and an elicitation phase where re-exposure triggers inflammatory symptoms (Larson et al., 2006; Sasseville, 2008; Xiao et al., 2018).

2.9) Healthcare Workers and their skin

Healthcare workers (HCWs) are at a higher risk of developing skin issues due to the frequent use of hand hygiene products. Studies indicate that alcohol-based hand rubs (ABHRs) can cause skin dryness, irritation, and dermatitis, particularly when used excessively or without adequate moisturization (Alsaidan et al., 2020; Duong et al., 2021). Additionally, the unique skin characteristics of black African females may increase their susceptibility to these conditions.

HCWs are especially vulnerable to occupational skin disorders (OSDs), including irritant contact dermatitis (ICD) and allergic contact dermatitis (ACD), because of their daily exposure to various skin irritants. Frequent handwashing removes lipids from the skin, while wet work can lead to overhydration. Prolonged use of gloves may cause occlusion, all of which compromise the skin's barrier integrity (Pittet et al., 2000; Kampf & Löffler, 2003; Yamamoto, 2012). These factors can worsen existing skin conditions, potentially leading to non-compliance with hand hygiene protocols. When HCWs experience skin irritation, they are less likely to adhere to strict hygiene practices, increasing the risk of spreading nosocomial infections, particularly during patient care tasks such as wound cleaning and bathing (Pittet et al., 2000; Kampf & Löffler, 2003).

2.10. Hand Hygiene

Hand hygiene refers to the practice of cleaning one's hands to significantly reduce the presence of potential pathogens. It is widely recognized as a simple yet effective strategy for lowering the rates of healthcare-associated infections (HAIs). High rates of HAIs are often considered indicators of poor compliance with hand hygiene protocols (WHO, 2009; Salama et al., 2013). Hand hygiene practices typically include the use of various products, as detailed in **Table 1**. Numerous guidelines are available to promote effective hand hygiene practices in healthcare settings (WHO, 2009; CDC, 2017).

Table 1. Hand hygiene products commonly used

Hand Hygiene product	Product Description	Reference
Alcohol-based hand rub (ABHR)	Alcohol-containing preparations typically contain ethanol, isopropanol, or n-propanol at concentrations of 60-90%.	WHO (2009), CDC (2020)
Antimicrobial soap (medicated)	Detergent soaps which contain an antiseptic agent.	WHO (2009)
Antiseptic agent	Antimicrobial containing substances such as chlorohexidine, chlorine derivatives, triclosan and alcohol.	Kampf & Kramer (2004)
Antiseptic hand wipe	Antiseptic-impregnated fabric or paper is used to wipe hands.	WHO (2009)
Detergent (surfactant)	Compounds that possess cleaning properties.	WHO (2009)
Plain soap	Detergent products which do not contain any added antimicrobial agents.	Kampf & Kramer (2004)
Waterless antiseptic agent	Antiseptic agents that do not require the use of exogenous water.	CDC (2020)

Hand hygiene is crucial for preventing the spread of infections, particularly in healthcare environments. Compliance with hand hygiene guidelines is essential, and choosing between washing with soap and water versus using alcohol-based hand rubs (ABHRs) can significantly affect skin health. While ABHRs effectively reduce microbial load, frequent use may lead to skin barrier disruption (Chopin-Doroteo and Krötzsch, 2022). The WHO recommends that ABHRs contain an alcohol concentration of at least 60% for effective hand sanitization (Singh et al., 2020).

Despite these recommendations, hand hygiene compliance remains relatively low in both developed and developing countries (WHO, 2021). An observational study by Boyce and Pittet (2002) found that healthcare workers (HCWs) washed their hands between five and thirty times per shift, with some nurses washing their hands up to one hundred times per shift. Factors contributing to HCWs' non-compliance with hand hygiene practices include skin irritation, understaffing, emergency situations, high workloads, supply shortages, and forgetfulness (Pittet, 2001). The most common hand hygiene methods include conventional handwashing with soap (either plain or antimicrobial) and water, as well as the use of ABHRs for sanitation (CDC, 2017; Vermeil et al., 2019).

The literature comparing the effects of detergent soaps and alcohol-based hand rubs on skin conditions is abundant and generally favours disinfection with alcohol-based hand rubs. However, no product is completely free of potential risks (WHO, 2009).

2.11). Effect of ABHRs on Skin Barrier Function

The effects of alcohol-based hand rubs (ABHRs) on skin barrier function have been the subject of extensive research. Studies have shown that repeated application of ABHRs can increase TEWL and decrease SCH, particularly with isopropanol-based formulations (Plum et al., 2020; Yüksel et al., 2022). On the other hand, ethanol-based ABHRs, especially those that are enriched with emollients, may help mitigate these adverse effects and improve skin hydration (Jing et al., 2020). Additionally, the use of ABHRs can impact the pH of the skin, which has implications for microbial defence and skin repair. (Hui-Beckman et al., 2022).

The impact of alcohol-based hand rubs (ABHRs) on skin barrier parameters is an important area of research, especially in light of the increased focus on hand hygiene since the COVID-19 pandemic. While ABHRs are well-regarded for their effectiveness in reducing microbial presence, extensive research has been conducted on how they affect skin barrier function. However, there is still a need to explore the effects of ABHRs on the skin barrier function specifically in black African females.

The two types of ABHRs investigated in this study are generally used in the healthcare sector in South Africa, namely Prime Safe® Alcohol Hand Rub (isopropyl-based) and Barrs Sterisol® (ethanol-based). The two ABHR products contain different constituents at varying concentrations; Prime Safe® Alcohol Hand Rub, used in private medical facilities, contains 23.4% de-ionised water, 75.15% isopropyl alcohol, and 1.4% glycerine. Barrs Sterisol® is used in public medical facilities and contains 0.5% chlorohexidine gluconate and 70% ethyl alcohol.

Literature on the influence of ABHRs on skin barrier function presents contrasting findings. Some studies report increased TEWL, decreased SCH and increased SS-pH, especially with more frequent ABHR applications, however, other research indicates that ABHRs do not significantly affect skin barrier function, with some suggesting that ABHR use might be beneficial to skin barrier health (Löffler et al., 2007, Plum et al., 2020, Tarka et al., 2019).

Tarka et al. investigated ABHR usage among HCWs and cosmetologists over one month and reported a decrease in TEWL along with no significant changes in SCH and sebum secretion, furthermore, these findings are supported by a 2018 review which found no evidence that ABHRs disrupt skin barrier function (Halm and Sandau, 2018, Tarka et al., 2019). Conversely, other studies reported negative skin effects and irritant dermatitis among HCWs due to frequent use of ABHRs (Araghi et al., 2020, Hui-Beckman et al., 2022).

As previously mentioned, since the COVID-19 pandemic, an influx of data on the subject followed as it received unprecedented attention, becoming a cornerstone of COVID-19. Given that previous literature has predominantly focused on the Caucasian population, the current study aims to investigate and compare the acute (8-hour) effects of two alcohol-based hand rubs on the skin barrier function in a black African female population.

2.12). Summary

In conclusion, the impact of alcohol-based hand rubs (ABHRs) on the skin barrier function of black African females is a significant area of research, especially within healthcare settings. While ABHRs are vital for infection control, it is important not to overlook their effects on skin health. Future studies should concentrate on the unique skin characteristics of this demographic and investigate ways to improve skin tolerability while ensuring effective hand hygiene practices are maintained.

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Author's Note

This manuscript has been prepared following general academic writing and formatting standards, as there is no specific journal designated for submission at this time. The structure, citation style, and presentation align with widely accepted guidelines to ensure clarity, coherence, and academic integrity.

For consistency, the APA referencing style will be followed throughout this manuscript, including in-text citations and the reference list. Any adjustments required to meet the specific formatting guidelines of a future journal, conference, or institutional repository will be made as needed.

CHAPTER 3: MANUSCRIPT DRAFT

The influence of two alcohol-based hand rubs on the skin barrier function of black African female students

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Abstract (263 words)

Effective hand hygiene remains paramount in infection and prevention programmes. Healthcare workers have an increased prevalence of skin irritation owing to frequent hand hygiene practices. Alcohol-based hand rubs (ABHRs) are often recommended for hand hygiene practices due to their effectiveness, practicality and safety profile. Research comparing the effects of detergent soaps and ABHRs on skin conditions is abundant; however, it is limited to Caucasian populations. Current research strongly favours disinfection by ABHRs over detergent soaps as they are better tolerated. **Aim:** This study aims to assess and compare the acute effects of ethanol-based and isopropyl-based hand rubs on skin barrier function in a black African female population. This demographic is often underrepresented in skincare research. **Method:** Thirty female African students with Fitzpatrick skin type V or VI, not suffering from any pre-existing skin pathology in the age range of 20-30 years, participated in the study. Two ABHR interventions were applied to randomised sampling sites on the volar forearm of the non-dominant arm at six measurement intervals over eight hours. Skin barrier function was assessed by standardised measurements such as transepidermal water loss (TEWL), stratum corneum hydration (SCH), and skin surface pH (SS-pH). **Results:** None of the ABHR interventions caused significant changes in TEWL, while SCH levels improved, particularly with ABHR1, indicating superior moisturising properties. Additionally, both ABHRs reduced SS-pH to a slightly acidic level, which is beneficial for skin barrier protection and repair. **Conclusion:** Both ABHRs (ethanol- and isopropyl-based) were well tolerated by the skin and did not disrupt the skin barrier of an African female population when applied acutely over eight hours.

Key Words: Alcohol-based hand rubs; healthcare workers; skin barrier function; transepidermal water loss; stratum corneum hydration, skin surface pH

BACKGROUND:

Proper hand hygiene is universally recognised as a fundamental and cost-efficient measure for preventing the spread of communicable diseases and infections. It has been proven to reduce infection rates among healthcare workers (HCWs) and the general population (Storr et al., 2017; Toney-Butler et al., 2024). Conventional methods for hand hygiene include handwashing with soap and water (plain/antimicrobial) and disinfection using waterless antiseptic agents. Hand hygiene practices are often amplified during a pandemic as part of enhanced infection-prevention interventions, as recently witnessed with the coronavirus disease 2019 (COVID-19) pandemic. This increases the potential risk of skin damage caused by the frequent use of hand hygiene products (Lan et al., 2020; Krishnamoorthy et al., 2023; Singh et al., 2020). However, hand hygiene compliance remains relatively low in both developed and developing countries (WHO, 2021).

Alcohol-based hand rubs (ABHRs), commonly known as hand sanitisers or waterless hand cleaners, are recommended in most instances for hand hygiene, except when the hands have been visibly soiled, which requires washing with soap and water. These hand rubs require less time to clean hands, are proven to be more microbiologically effective, cause less visible skin irritation, and less disruption of the skin barrier of healthy skin compared to traditional handwashing with soap and water (Pedersen et al., 2005; Trampuz and Widmer, 2004). Hand rub formulations generally contain alcohol, usually ethanol, isopropanol, n-propanol or a combination of these alcohols. Alcohol is the active ingredient in ABHR formulations and is responsible for its antimicrobial activity. It reduces pathogen activity by denaturing proteins; consequently, it also strips the skin of its natural oils and moisture. The alcohol in ABHRs destroys the cell membrane of bacteria and the envelope of viruses (including SARS-CoV-2) (Golin et al., 2020; Larson et al., 1991).

The formulation of ABHRs significantly influences their effects on skin barrier function, which makes some formulations of ABHRs more tolerable than others (Cartner et al., 2017). Several invasive and non-invasive methods exist to assess skin barrier function. The measurement of Transepidermal Water Loss (TEWL) is most widely used and often accompanied by other biophysical measurement parameters such as Stratum Corneum Hydration (SCH), Skin Surface pH (SS-pH), tape stripping, and other less widely used methods such as Raman spectroscopy to assess skin barrier function (Antonov et al., 2016; Kleesz et al., 2012). Transepidermal water loss is the most commonly used objective test for assessing the skin's barrier function, especially in individuals with skin conditions like atopic dermatitis, which is associated with impaired skin barrier function (Akdeniz et al., 2018; Pal, 2023). Transepidermal water loss is the quantity of water vapour which passively diffuses from the stratum corneum to the surrounding environment,

often expressed in g/m²/h. Water loss is part of normal skin metabolism; due to a water vapour pressure gradient on both sides of the skin, TEWL is directly proportional to the skin's hydration status (Campbell, 2004; Maibach and Honari, 2014). It is influenced by various endogenous and exogenous factors like humidity, temperature, age, anatomical location, circadian rhythm, and skin health, to mention a few (Braun-Falco and Korting, 1986; Engebretsen et al., 2016; Maibach and Honari, 2014; Plessis et al., 2013a). Skin surface pH is known to affect the dissolution and partitioning of chemicals with which it comes into contact, thereby influencing its exposure profile, which increases the risk of skin disease pathology (Stefaniak et al., 2013). Skin surface pH measurements are essential to understanding skin health and barrier function. Contradictory evidence exists regarding SS-pH values across different races and sexes, more recent literature reports normal SS-pH to be in the range of 4.1 to 5.8 across most anatomical areas (Segger et al., 2008, Jung et al., 2012, Young et al., 2019). Atopic dermatitis often presents elevated SS-pH values, which fall in the neutral to alkaline range. Upon experimental disruption of the skin barrier, SS-pH values generally increase and return to normal ranges after barrier repair has occurred. A lower pH commonly corresponds with decreased TEWL and higher SCH values in healthy populations (Lambers et al., 2006; Darlenski et al., 2009; Proksch, 2018). Stratum corneum hydration refers to the water content in the uppermost skin layer, more commonly known as the stratum corneum. Hydration is essential to skin health and significantly influences its physical and mechanical properties (Manfredini et al., 2013; Majumdar et al., 2017; Plessis et al., 2013b). SC hydration measurements are influenced by particular variables such as ethnicity/race, anatomic site and even gender (Darlenski and Fluhr, 2012; Man et al., 2009).

The influence of ABHRs on skin barrier parameters is a critical research area, especially given the heightened emphasis on hand hygiene since the COVID-19 pandemic. While ABHRs are highly regarded for their ability to lower microbial presence, considerable research has been conducted into how they affect skin barrier function. However, there remains a need to understand the effects of ABHRs on the skin barrier function of black African females. Some studies report increased TEWL, decreased SCH and increased SS-pH, especially with more frequent ABHR applications. However, other research indicates that ABHRs do not significantly affect skin barrier function, with some suggesting that ABHR use might be beneficial to skin barrier health (Löffler et al., 2007; Plum et al., 2020; Tarka et al., 2019). Tarka et al. investigated ABHR usage among HCWs and cosmetologists over one month and reported a decrease in TEWL along with no significant changes in SCH and sebum secretion, furthermore, these findings are supported by a 2018 review which found no evidence that ABHRs disrupt skin barrier function (Halm and Sandau, 2018; Tarka et al., 2019). Conversely, other studies reported negative skin effects and irritant

dermatitis among HCWs due to frequent use of ABHRs (Araghi et al., 2020; Hui-Beckman et al., 2022).

Given that previous literature has predominantly focused on the Caucasian population, the current study aims to investigate and compare the acute (8-hour) effects of two alcohol-based hand rubs on the skin barrier function in a black African female population. This demographic has been underrepresented in previous research, especially since there is a predominance of females in the healthcare setting. This study aims to provide data which may be considered when developing effective skincare strategies and treatments.

Materials and methods

Study Design:

The study was based on quantitative and repeated measurements to determine the effect of two types of ABHRs on selected skin barrier function parameters. Skin barrier function was evaluated on the volar aspect of the non-dominant forearm using non-invasive standardised measurement techniques to determine TEWL, SCH and SS-pH over eight hours in a simulated environment. The volar forearm of the non-dominant arm was chosen as the measurement area for several reasons: it provides a larger surface area, is less exposed to external influences compared to the hands, is easily accessible making it practical and comfortable for measurements and has minimal hair interference (Kleesz et al., 2012, Houben et al., 2006).

The ABHRs used in the study were Barrs Sterisol® (ethanol-based) (ABHR1) and Prime Safe® Alcohol Hand Rub (isopropyl-based) (ABHR2). Both ABHR products at the time of the study were currently in use in the healthcare sector in South Africa, with ABHR2 used in the private medical sector and ABHR1 in the public medical sector. The two ABHR products contain different constituents at varying concentrations; Prime Safe® Alcohol Hand Rub, used in private medical facilities, contains 23.4% de-ionised water, 75.15% isopropyl alcohol, and 1.4% glycerine. Barrs Sterisol® is used in public medical facilities and contains 0.5% chlorohexidine gluconate and 70% ethyl alcohol (Table 1).

Table 1. Chemical composition of the selected alcohol-based hand rubs:

Alcohol-based hand rub 1 Barrs Sterisol®		Alcohol-based hand rub 2 Prime Safe®	
Ethanol	70%	Isopropyl	75.5%
Chlorohexidine	<5%	De-ionised water	23.4%
Colour	<5%	Glycerine	1.4%
Water-purified	20%		
Glycerine	*unknown		

Source: Adapted from Sterisol (2024) and Steritech (2024).

Study Population

Thirty female African students, aged 20-30 years, with Fitzpatrick skin type IV to VI, as observed by the researcher, were included in the study. The Fitzpatrick scale represents six different skin types based on skin colour and reactivity to sun exposure. The skin colour ranges from skin type I (very fair) to skin type VI (very dark) and is dependent on the subjects' response to ultraviolet light exposure (burning/tanning). Participant skin type was assessed by the researcher using the Fitzpatrick chart. If a participant's skin type fell outside the IV to VI range, it was documented accordingly. This classification is key for ensuring consistency in assessing individual variations in skin response to environmental exposures, which may influence barrier function and may aid in comparing skin reactions across different exposure conditions (Gupta & Sharma, 2019).

Light skin types are typically more prone to burns and tan slower, while darker skin tan easily and are more resistant to sunburn (Sachdeva, 2009). Black African female students were selected as this demographic is quite often overlooked in skin research, with a preponderance of females existing in the healthcare field. The chosen study population consists of students who are

generally in an age group considered to be healthy, as many disorders are associated with older age. Skin diseases are more prevalent among ageing populations (Blume-Peytavi et al., 2016; SANC, 2017; Narla et al., 2023). In addition, selecting this specific age range allowed a larger pool of participants to be recruited. Participants in the 20-30 age range were free of pre-existing skin pathology and enrolled at a tertiary institution participating in the respective study. Participants were instructed to avoid washing and applying cosmetic products on their non-dominant arms for at least 12 hours before measurements and to avoid wearing clothing that covers or obstructs measurements on the respective arm on the sampling day. Consumption of alcohol and caffeine (coffee and energy drinks) containing beverages was prohibited for at least 12 hours before measurements and only allowed after completion of the experiment.

Biophysical measurement

Participants acclimatised in a climate-controlled room for 20 minutes (ambient temperature between 20 – 22 °C and relative humidity between 40 and 60% before any measurements were recorded. A short questionnaire was completed during the acclimatisation period to determine the volunteer's adherence to the sampling guidelines. Any failed adherence resulted in the participant joining the study on another day. Factory Calibrated Courage + Khazaka electronic GmbH (Germany) instruments were used to measure selected skin parameters. An open chamber Tewameter TM 300 (Courage & Khazaka Electronic, Cologne, Germany) was used to assess Transepidermal Water Loss (TEWL). A Corneometer CM 825 (Courage & Khazaka Electronic, Cologne, Germany) and a Skin surface pH meter PH 905 (Courage & Khazaka Electronic, Cologne, Germany) were used to measure the hydration level of the skin surface (through capacitance) and skin surface pH respectively. All the instruments/probes were connected to a Multi-Probe Adapter (MPA) system. The measurements were taken between 07:00 and 16:00; volunteers visited the lab at various time intervals for the measurement sessions, which lasted approximately 40 minutes per session. The sampling area was marked with an alcohol-free marker pen using a customised stencil, as illustrated in Figure 1 on the volar aspect of the forearm. The Latin square design was applied in this study to ensure the randomisation of the sampling area. These application zones, as seen in Fig 1 (b), were randomly alternated on the different participants, i.e., for participant number one, the zone demarcated as 'A' was assigned as the control area, zone 'B' for ABHR1, and 'C' for ABHR2. For the succeeding participant zone: 'A' = ABHR1, 'B' = ABHR2, and 'C' = Control. Subsequent participants, therefore, had randomised measurement sites for the respective interventions. The three zones were spaced 2 cm apart to prevent cross-contamination of the ABHRs. Within each zone, three adjacent measurements were taken for each biophysical parameter, and the average was determined for statistical analysis.

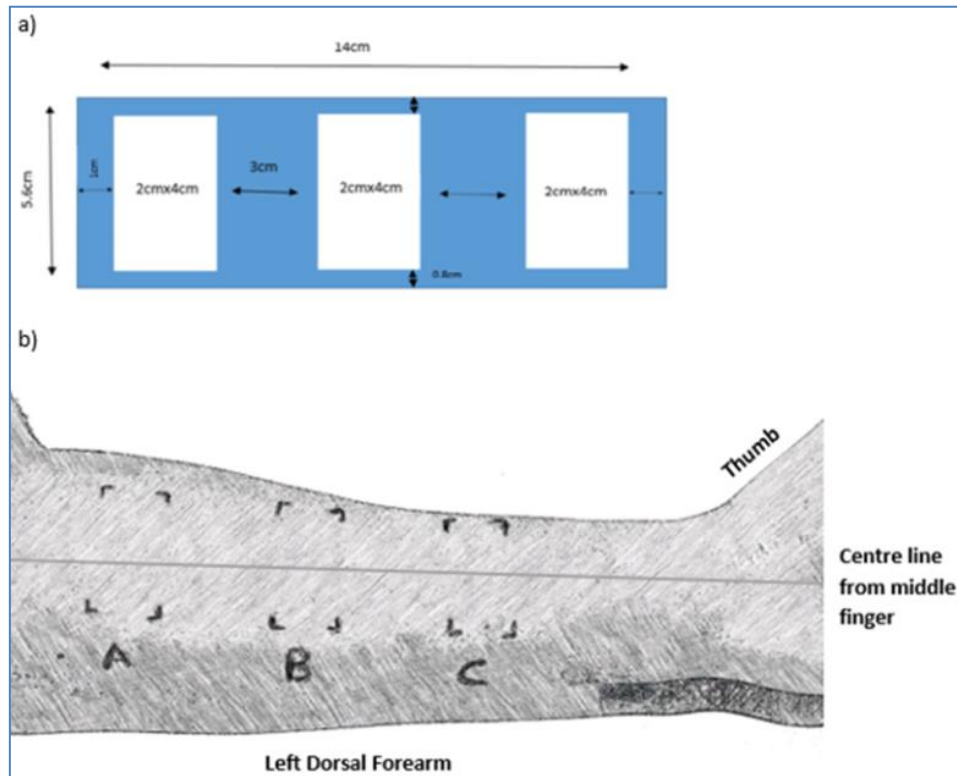


Figure 1. Schematic representation of **a)** stencil used to mark measurement sites and **b)** marked measurement sites on non-dominant volar forearm. Locations of AHBR interventions and control sites were randomised for respective participants through Latin square design.

Following baseline recordings, a pipette was used to administer 0.03 ml of ABHR onto each respective site; the researcher used new non-latex-based disposable gloves for each participant's visit to apply the ABHR, ensuring consistency. The application process involved 20 circular rotations, followed by a two-minute wait for the area to dry after each measurement. This procedure was repeated at various measurement intervals over eight consecutive hours, as depicted below in Figure 2.

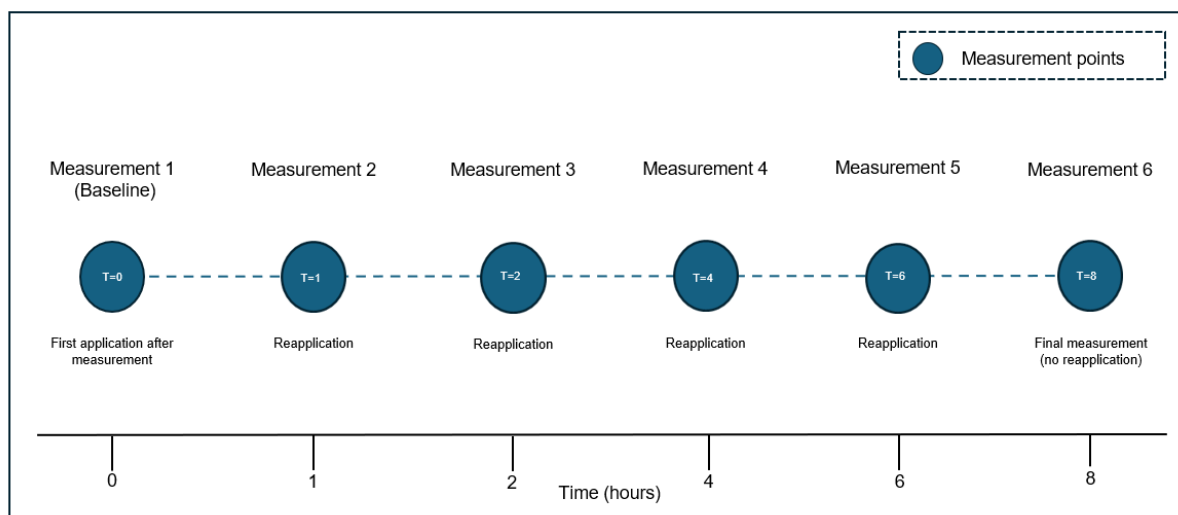


Figure 2. Measurement strategy. The measurement intervals were over eight hours, comprising six points ranging from T = 0 to T = 8. Measurements two through five involved reapplications directly after measurements, while measurement six was the final measurement without reapplication. Measurement one was the baseline, followed by the initial application.

Statistical Analysis

Statistical analyses were performed using IBM® Statistical Package for Social Sciences (SPSS)® Statistics for Windows, version 29 (IBM Corp., Armonk, N.Y., USA). The assumptions of normality and homogeneity of variance were evaluated based on the model's standardised residuals. A histogram of the residuals was used to evaluate normality, and the predicted values were plotted against the standardised residuals to evaluate the homogeneity of variance.

Repeated-measures analysis of variance (ANOVA) within a general linear model (GLM) framework was performed to investigate changes in skin barrier function parameters (TEWL, SCH, and SS-pH) over time (0,1,2,4,6,8 hours) for the respective interventions (Control, ABHR1, and ABHR2). Post-hoc pairwise comparisons using Bonferroni corrections were used to identify significant changes within each skin barrier parameter at specific time points. Additionally, the different interventions were compared at each measurement interval using Bonferroni-adjusted comparisons for the interaction between group and time. The significance level was set at $\alpha = 0.05$. For the statistical analysis of SS-pH, values obtained were converted to hydrogen ion concentration ($[H^+]$) through the mathematical operation of antilog ($- \text{pH}$). These values were converted back to pH once statistical analysis was performed. For suitable comparisons of pH results from published papers, it should be determined which pH averaging technique was used. If authors do not state that the $[H^+]$ averaging technique was used, this often suggests direct averaging of pH (Boyd et al., 2011).

Ethics consideration

Ethics approval (NWU-00005-19-A1) was obtained from the Health Research Ethics Committee (HREC) of the North-West University Potchefstroom Campus, South Africa. The experimental objectives and procedures were clarified, and informed consent was obtained from volunteers before the commencement of the study. Participation was voluntary, and withdrawal was permitted at any time. Measurements were conducted in a private lab (F12, room 117), with participants identified by unique numbers to maintain confidentiality. All data was securely stored (locked cabinet and password-protected/cloud storage) and will be destroyed after 10 years.

Results

This study explored the impact of two ABHRs on skin barrier function, specifically TEWL, SCH, and SS-pH, over time in an apparently healthy African female student within a clinically controlled environment. The primary objective was to assess how each hand rub intervention affected these biophysical parameters, followed by a comparative analysis of the two interventions.

Profile plots were used to visualise the temporal changes for each measured parameter across time for each intervention. They were generated using corresponding means and error bars to aid interpretation.

Figures 3 – 5 illustrate the selected biophysical parameters of the volar forearm in response to two applied interventions over an eight-hour period.

TEWL measurements over time by alcohol based hand rub intervention

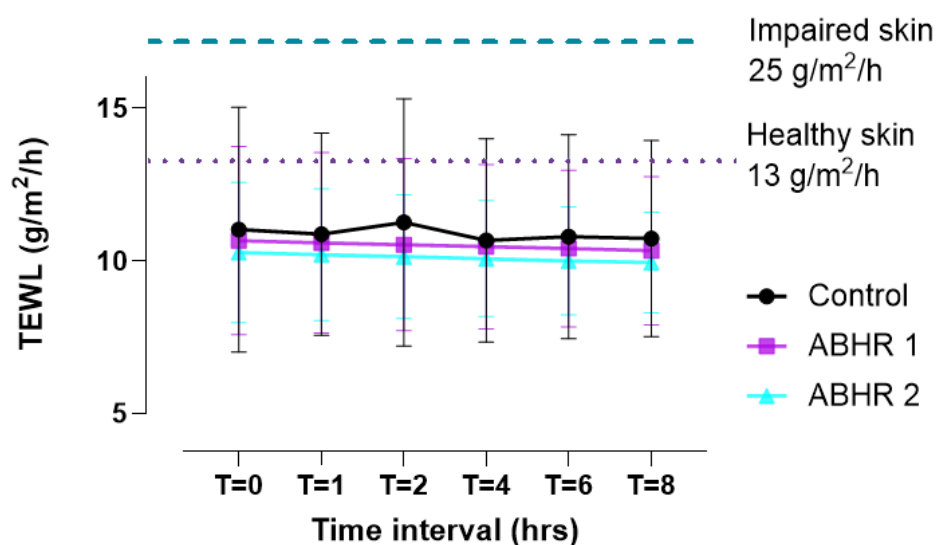


Figure 3: The graphs present the study's key findings for TEWL measurements of three interventions over time intervals. TEWL values for the control group (black line), ABHR 1 (purple line), and ABHR 2 (blue line) at baseline (T=0) and subsequent time intervals (T = 1, T = 2, T = 4, T = 6, T = 8). Error bars indicate variability across measurements. P values ≤ 0.05 are considered significant. The dotted lines represent TEWL benchmarks for healthy skin ($13 \text{ g/m}^2/\text{h}$) and normal skin ($25 \text{ g/m}^2/\text{h}$).

The TEWL measurements over time for the intervention groups are shown in Figure 3. At baseline (T = 0), all the groups, including the control, ABHR1 and ABHR2, exhibited TEWL values within the healthy skin range ($<13 \text{ g/m}^2/\text{h}$). TEWL values for the control group showed slight fluctuations between $10.67 \text{ g/m}^2/\text{h}$ and $11.26 \text{ g/m}^2/\text{h}$ but remained consistent around $11 \text{ g/m}^2/\text{h}$. For ABHR1, TEWL values remained consistently within the healthy range; there was a slight decline from $10.66 \text{ g/m}^2/\text{h}$ to $10.33 \text{ g/m}^2/\text{h}$ after the eight-hour interval. Furthermore, the TEWL profile reported no significant change. Like ABHR1, ABHR2's TEWL values remained relatively stable over the measurement intervals. After 8 hours, TEWL values slightly declined from $10.27 \text{ g/m}^2/\text{h}$ to $9.94 \text{ g/m}^2/\text{h}$. However, no significant differences were noted between ABHR2 and the control or ABHR1, indicating that ABHR2 is comparable to ABHR1 in maintaining skin barrier integrity. Both hand rub interventions demonstrated no significant change in TEWL values over the eight-hour observation period.

SCH measurements over time by alcohol based hand intervention

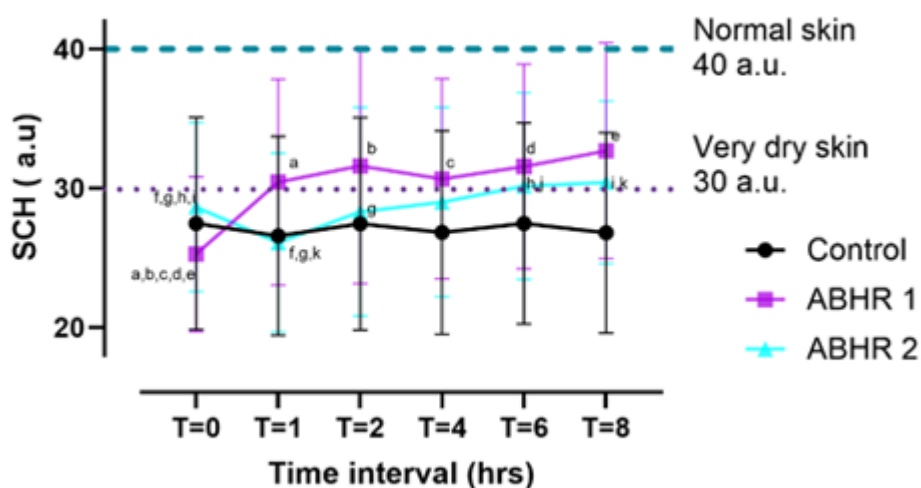


Figure 4 The graphs present the study's key findings for SCH measurements of three interventions over time intervals. SCH values for the control group (black line), ABHR 1 (purple line), and ABHR 2 (blue line) at baseline (T=0) and subsequent time intervals (T = 1, T = 2, T =

4, T = 6, T = 8). Error bars indicate variability across measurements. The corresponding alphabetic letters (e.g., “a”, “b”, “c”) denote statistically significant differences between results from respective time points. P values ≤ 0.05 are considered significant. The dotted lines represent SCH benchmarks for very dry skin (30 a.u.) and normal skin (40 a.u.).

Figure 4 summarizes SCH measurements. At baseline (T = 0), all the groups presented SCH values around the threshold for very dry skin (~30 a.u.). SCH values for the control group remained consistently stable and averaged close to 27 a.u. In contrast, SCH values for the ABHR1 intervention showed an increasing trend over time. Statistically significant increases were observed at several time intervals, as denoted by the alphabetic annotations (e.g., “a,” “b,” etc.). At the end of the study (T = 8), SCH values were around the threshold for normal hydration levels (40 a.u.). ABHR2 also demonstrated a gradual increase in SCH over time. At baseline, the hydration values were 26.10 a.u., which increased to 30.43 a.u. after 8 hours. Significant increases can be seen across numerous measurement intervals as depicted in Figure 4. The results indicate a less pronounced increase in SCH for ABHR2 compared to ABHR1; however, the difference between the two respective hand rub interventions was insignificant.

SS-pH measurements over time by alcohol based hand rub

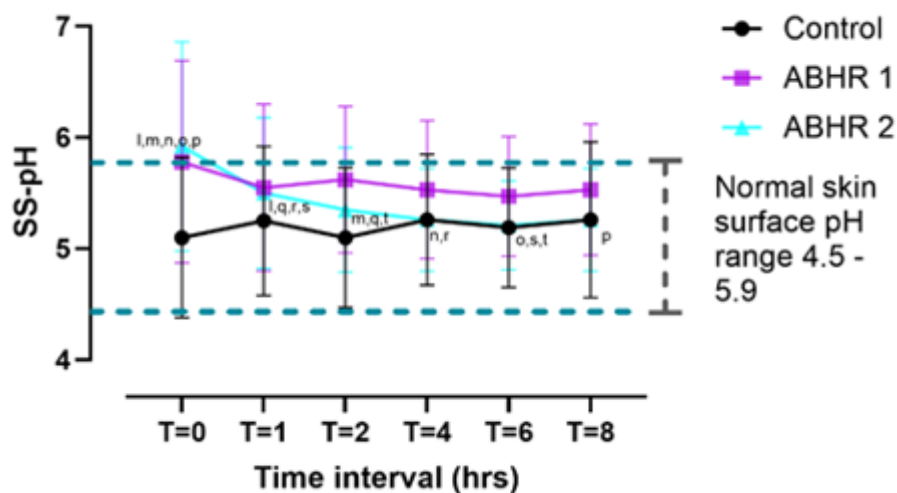


Figure 5 The graphs present the study's key findings for SS-pH measurements of three interventions over time intervals. SS-pH values for the control group (black line), ABHR 1 (purple line), and ABHR 2 (blue line) at baseline (T=0) and subsequent time intervals (T = 1, T = 2, T = 4, T = 6, T = 8). Error bars indicate variability across measurements. The corresponding alphabetic letters (e.g., “a”, “b”, “c”) denote statistically significant differences between results

from respective time points. P values ≤ 0.05 are considered significant. The dotted lines represent SS-pH benchmarks for the normal SS-pH range (4.5-5.9).

The SS-pH results, as illustrated in Figure 5, highlight the stability of the ABHR interventions. All groups began with SS-pH values within the normal physiological range (4.5–5.9). Over time, minor fluctuations were noted; with ABHR 1, SS-pH values were recorded at 5.78 at the start of the study and then slightly decreased to 5.53 at T=8. ABHR 2 demonstrated a significant decrease in SS-pH across various measurement intervals, as denoted by the alphabetic annotations (e.g., “a,” “b,” etc.). Baseline measurements were at 5.92, which decreased to 5.26 at the end of the study (T = 8). All values were within the healthy pH range. However, the decline moved it closer to the lower end of the normal pH range, consistently maintaining a stable SS-pH. In contrast, the control group averaged around 5.2, confirming no disruption of the skin's natural pH.

Discussion

The study assessed and compared the acute influence of ethanol-based (ABHR1) and isopropyl-based (ABHR2). interventions on the skin barrier function of black African female students. Both ABHR1 and ABHR2 showed favourable outcomes on the biophysical parameters, indicating that they were well-tolerated by the skin and did not disrupt the skin barrier when applied acutely over eight hours. These findings underscore the safety of ABHR interventions and have significant implications for hand hygiene practices in healthcare settings.

In all groups, the baseline TEWL measurements were below the upper threshold for healthy skin ($<13 \text{ g/m}^2/\text{h}$) and well below the threshold of a compromised skin barrier ($25 \text{ g/m}^2/\text{h}$). TEWL values remained below this range for the entirety of the repeated measurements, T= 1 – 8). These findings imply that no significant change in TEWL occurred over the eight hours and that all participants commenced the study with a relatively intact skin barrier function. Both hand rub interventions kept TEWL levels comparable to the control group, with only a slight, non-significant decline after eight hours. This suggests that they are compatible with the skin barrier function and may even have a beneficial effect.

These findings are consistent with existing literature, which indicates that well-formulated ABHRs do not compromise skin barrier function (Chopin-Doroteo and Krötzsch, 2023; Oluwatuyi et al., 2020). The preservation of TEWL levels reinforces that these hand rub products can be safely used in high-frequency application settings, such as healthcare environments, without negatively impacting skin health. Healthy, intact skin restricts excessive water loss; conversely, once the skin barrier is impaired, the rate of water loss significantly increases, as commonly observed in

atopic skin. Transepidermal water loss measurements assess the skin condition during various exposures and allow for the early detection of barrier disruption even before visible damage.

Significant differences regarding SCH were observed between the interventions and the control group. The control group displayed low hydration levels indicative of dry skin, while ABHR1 significantly improved hydration levels, reaching approximately 40 a.u. after eight hours. This improvement confirms the presence of emollients contained in ABHR1, which enhanced skin hydration. This benefits individuals with pre-existing dry skin conditions, improving their skin health and increasing hand hygiene compliance (Kampf et al., 2005). Furthermore, ABHR2 also improved SCH, but to a lesser extent than ABHR1. The hydrating effect is likely related to the humectant concentration in each hand rub and the type of alcohol, with ethanol being suggested to be more tolerable (Cartner et al., 2017; Tasar et al., 2021). Stratum corneum hydration plays a significant role in determining the permeability of the stratum corneum, the enzymatic activity within it, the skin's mechanical properties, and its overall appearance. The results emphasise the importance of selecting hand rub formulations containing emollients which alleviate dryness associated with frequent use (Jing et al., 2020).

Regarding SS-pH measurements remained within the acceptable normal range for all interventions, indicating that the skin's natural acid mantle was not impaired. Alcohol-based hand rub 2 demonstrated a significant acidifying effect, causing the pH to drop from 5.92 to 5.26. Although this decrease was statistically significant, the final pH value remained within a healthy range. This is important because a lower pH is generally beneficial for the skin, contributing to improved barrier function, hydration, and antimicrobial defence., which is especially relevant in healthcare settings (Brooks et al., 2024, Proksch, 2018).

The research findings are consistent with previous studies, indicating that using ABHR does not negatively affect barrier function and may provide additional benefits. Skin water loss remained stable, hydration levels improved to healthy values, and the acidic environment of the skin was potentially advantageous. This suggests that the use of ABHR interventions could not only maintain but also potentially enhance skin health (Ahmed-Lecheheb et al., 2012; Löffler and Kampf, 2008; Yüksel et al., 2022).

Considering these findings, it is important to consider the broader implications of hand hygiene practices in diverse populations. Future studies should investigate the long-term effects of ABHRs on skin barrier function across different demographics, including variations in skin types and conditions. Additionally, examining the cumulative effects of frequent ABHR use in high-stress environments, such as hospitals, could provide valuable insights for optimising hand hygiene protocols while preserving and improving skin health.

Conclusion

In conclusion, this study demonstrated that both ethanol-based (ABHR1) and isopropyl-based (ABHR2) hand rubs, when applied acutely, did not negatively impact skin barrier function as measured by TEWL. Alcohol-based hand rub 1 significantly improved skin hydration (SCH), likely due to its emollient content, while ABHR2 also showed a hydrating trend, although less pronounced. While ABHR2 induced a statistically significant decrease in skin surface pH, all values remained within the normal range. These findings support the safe acute use of both ABHR formulations for hand hygiene, with ABHR1 potentially offering added benefits for dry skin. Future research should explore the long-term effects of ABHR use in diverse populations and high-frequency application settings. Additionally, exploring the impact of different ABHR formulations with varying alcohol concentrations and emollient profiles would provide valuable insights for optimising hand hygiene practices while minimising potential adverse effects on skin health.

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CHAPTER 4: SUMMARY OF THE MAIN FINDING, CONCLUSION AND RECOMMENDATIONS

4.1 Introduction

This concluding chapter provides an overview of the study's key findings, evaluates its relevance to the research objectives, and discusses its broader implications for public health and product development. It also presents recommendations for future research and practical applications. The study investigated the acute (eight-hour) influence of two ABHR formulations, specifically ethanol-based and isopropanol-based hand rubs, on selected skin barrier parameters: TEWL, SCH, and SS-pH. These biophysical parameters are critical indicators of skin health, particularly for populations frequently exposed to irritants due to occupational or environmental factors.

4.2 Research Objectives

Skin barrier function was evaluated on the volar aspect of the non-dominant forearm using standardised, non-invasive measurement techniques to determine TEWL, SCH, and SS-pH over eight hours in a controlled environment. The research objectives were:

- 1) To establish the influence of two types of ABHRs on the skin barrier function of a black African female population over eight hours as determined by TEWL, SCH, and SS-pH.
- 2) To compare the effects of ethanol-based and isopropyl-based hand rub formulations on the skin barrier function, specifically TEWL, SCH, and SS-pH

4.3 Hypotheses

It is hypothesised that both ABHR1 and ABHR2 will increase transepidermal water loss (TEWL) and skin surface pH (SS-pH), while decreasing stratum corneum hydration (SCH) over the six measurement intervals (eight-hours).

For ABHR1, TEWL values remained consistently within the healthy range; there was a slight decline from 10.66 g/m²/h to 10.33 g/m²/h after the eight-hour interval. Furthermore, the TEWL profile reported no significant change. Like ABHR1, ABHR2's TEWL values remained relatively stable over the measurement intervals. After 8 hours, TEWL values slightly declined from 10.27 g/m²/h to 9.94 g/m²/h. SCH values for the ABHR1 intervention showed an increasing trend over time. At the end of the study (T = 8), SCH values were around the threshold for normal hydration levels (40 a.u.). ABHR2 also demonstrated a gradual increase in SCH over time. At baseline, the hydration values were 26.10 a.u., which increased to 30.43 a.u. after 8 hours. All groups began with SS-pH values within the normal physiological range (4.5–5.9). Over time, minor fluctuations were noted, with ABHR 1, SS-pH values were recorded at 5.78 at the start of the study and then slightly decreased to 5.53 at T=8. ABHR 2 demonstrated a significant decrease in SS-pH across various measurement intervals. Baseline measurements were at 5.92, which decreased to 5.26 at the end of the study (T = 8).

(i) Published studies on the effects of alcohol-based hand rubs (ABHRs) on skin barrier function have reported increased transepidermal water loss (TEWL), decreased stratum corneum hydration (SCH) and increased skin surface pH (SS-pH) , suggesting potential impairment of skin barrier integrity. Based on these findings, it is hypothesised that both ABHR1 and ABHR2 will significantly affect the skin barrier parameters (Increased TEWL, decreased SCH and increased SS-pH).

The hypotheses, which speculated that both ABHR1 and ABHR2 would increase TEWL and SS-pH while decreasing SCH, are rejected. The findings of this study contradict these initial predictions. Specifically, neither ABHR1 nor ABHR2 demonstrated a significant increase in TEWL over the eight-hour observation period. In fact, TEWL values remained relatively stable for both alcohol-based hand rubs, comparable to the control group, suggesting no compromise to skin barrier integrity.

(ii) Comparative studies of alcohol-based hand rubs have shown variability in their effects on skin function barrier parameters. Based on these findings, it is hypothesised that ABHR1 will have a more pronounced negative impact on TEWL, SCH, and SS-pH compared to ABHR2.

While statistically significant increases in SCH were observed for both ABHR1 and ABHR2 across several measurement intervals, the magnitude of the increase was greater for ABHR1, indicating a more pronounced hydrating effect. Although ABHR2 also improved SCH, the difference between the two hand rubs was not statistically significant. Finally, regarding SS-pH, while a statistically significant *decrease* was observed, particularly with ABHR2, all measured pH values

remained within the normal physiological range. Therefore, while ABHR2 did acidify the skin surface slightly, the change was within acceptable limits. The hypothesis that ABHR1 would have more negative effects on skin function parameters compared to ABHR2 is also rejected, as the observed differences were primarily in terms of hydration benefits, with ABHR1 showing a greater hydrating effect.

4.4 Summary of the main findings

The TEWL values for ABHR1 and ABHR2 remained relatively stable over the measurement intervals with no significant changes over time, as well as by the control group and the two interventions. For instance, there was a slight decline from 10.66 g/m²/h to 10.33 g/m²/h after the eight-hour interval for the ABHR1. The TEWL values for ABHR2 also slightly declined from 10.27 g/m²/h to 9.94 g/m²/h. The SCH for ABHR2 was less pronounced than ABHR1; however, the difference between the two hand rub interventions was insignificant. The SCH increased from 26.10 a.u. at baseline to 30.43 a.u. after 8 hours over time. Regarding ABHR 1, SS-pH values were recorded at 5.78 at baseline and then slightly decreased to 5.53 at T=8. ABHR 2 demonstrated a significant decrease in SS-pH, with a baseline measurement of 5.92, which decreased to 5.26 at the T = 8 (Figure 1).

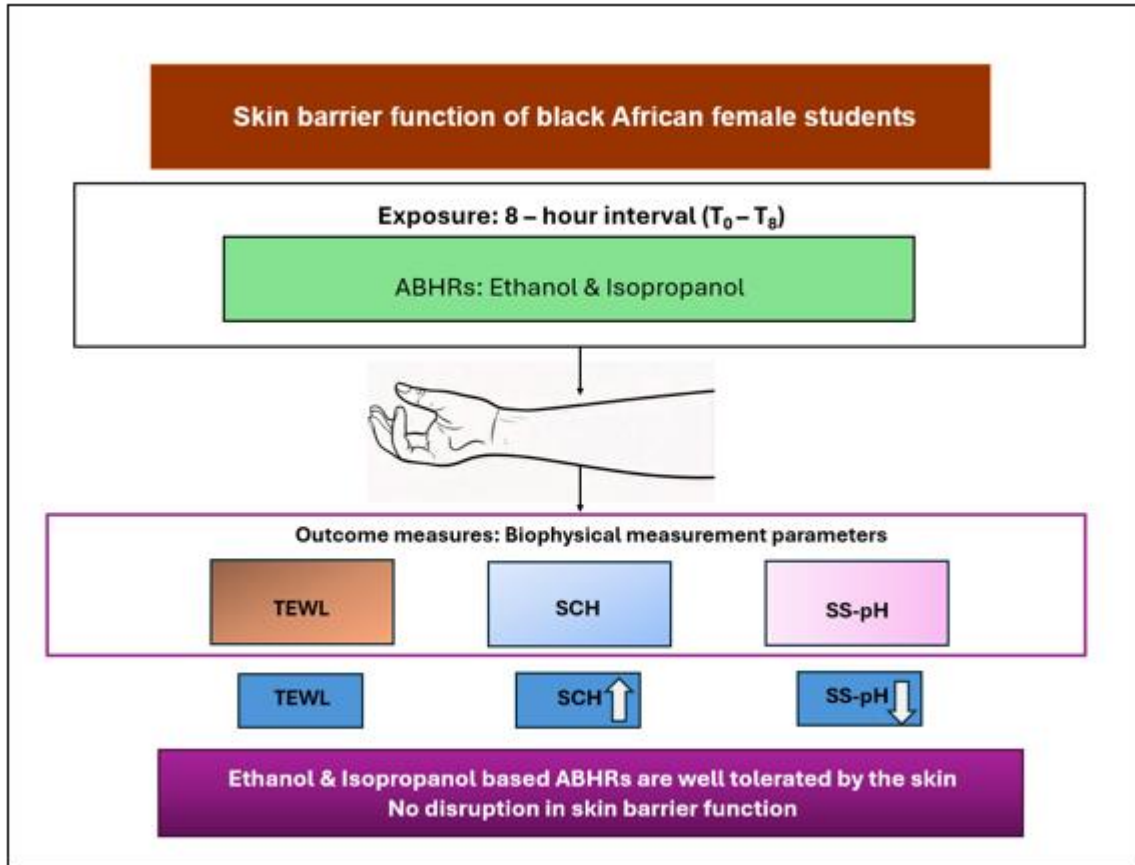


Figure 1. Summary of the effects of ethanol- and isopropanol-based alcohol-based hand rubs (ABHRs) on the skin barrier function of black African female students over an 8-hour exposure period.

4.5 Discussion of the Main Findings

The findings indicate that both ABHRs maintained TEWL within healthy ranges over the eight hours, with no significant differences between the two formulations or the control group. TEWL is directly related to the hydration status of the skin (Campbell, 2004; Maibach and Honari, 2014), and it can be influenced by humidity, temperature, age, anatomical location, circadian rhythm (Engebretsen et al., 2016; Maibach and Honari, 2014; Plessis et al., 2013a). Moreover, TEWL measurements assess the skin condition during various exposures and allow for the early detection of barrier disruption even before visible damage. Healthy, intact skin limits excessive water loss; conversely, once the skin barrier is impaired, the rate of water loss significantly increases, as commonly observed in atopic skin. Additionally, ethanol is beneficial for sanitising against microbiological organisms (Kampf, 2018). Emollients or other skin conditioners can

correct skin dryness resulting from alcohol exposure (Ahmed-Lecheheb et al., 2012; Kanlayavattanakul, Rodchuea, Lourith, 2012; Ionidis et al., 2016).

ABHR1 significantly improved SCH, achieving hydration levels indicative of healthy skin, while ABHR2 also improved SCH to a lesser extent. SCH measures water content in the uppermost skin layer - stratum corneum (Manfredini et al., 2013, Mojumdar et al., 2017, Plessis et al., 2013b). SC hydration may be affected by ethnicity/race, anatomic site and gender (Darlenski and Fluhr, 2012, Man et al., 2009) as well as the ambient relative humidity as the stratum corneum is exposed to the atmosphere (Proksch et al., 2008). The integrity of the skin barrier protects against unwanted water loss from the internal environment and maintains the optimal hydration of the epidermis (O'goshi and Serup, 2005). The hydration status of the SC provides information on the current condition of the skin's barrier function. Skin hydration represents the water content of the epidermis and dermis. As water content increases in the SC, it causes a change in its dielectric properties (Denzinger et al., 2020). SCH plays a significant role in determining the permeability of the stratum corneum, the enzymatic activity within it, the skin's mechanical properties, and its overall appearance (Constantin et al., 2014, Mayrovitz, 2023)

Both formulations preserved SS-pH within the physiological range, while ABHR2 had a beneficial acidifying effect that supports barrier integrity and reduces the risk of irritation and infection (Proksch, 2018; Lambers et al., 2006). Cutaneous barrier repair and antimicrobial defence are related to the acidic characteristics of the skin. Furthermore, SS-pH is known to affect the dissolution and partitioning of chemicals with which it comes into contact, thereby influencing its exposure profile; this increases the risk of skin disease pathology (Stefaniak et al., 2013). The normal SS-pH range is 4.1 to 5.8 (Segger et al., 2008, Jung et al., 2012, Young et al., 2019) while atopic dermatitis often presents with higher SS-pH values, which fall in the neutral to alkaline range. A lower pH commonly corresponds with decreased TEWL and higher SCH values in healthy populations (Lambers et al., 2006, Darlenski et al., 2009, Proksch, 2018). These results suggest that both ABHRs are well-tolerated and do not disrupt the skin barrier, with ABHR1 providing slightly better hydration benefits.

The research aimed to address a significant gap in understanding the effects of ABHRs on the skin barrier function of black African females, an underrepresented demographic in dermatological studies. This focus is essential given the increased reliance on ABHRs in healthcare and other professional settings, where frequent hand hygiene is essential. The findings support the continued use of ABHRs in healthcare, emphasising their safety and efficacy while highlighting the need for tailored formulations to reduce adverse effects and improve skin tolerance. The results align with the research objectives and underscore the importance of

developing inclusive, skin-friendly hand hygiene products. Integrating emollient-enriched ABHRs into healthcare protocols can balance effective pathogen control with preserving skin health. This chapter examines these findings, their implications for diverse populations, and the necessity of future research to explore long-term effects, environmental factors, and product optimisation.

4.5 Challenges and Mitigation Strategies

During the research process, we encountered several challenges:

- **Participant recruitment**
The study population was limited to black African female students aged 20 to 30. This narrow demographic focus made recruitment challenging. In addition, enrollment required a significant time commitment for multiple laboratory visits. One participant enlisted in the study but later dropped out because of other obligations; that data was excluded.
- **Adherence to pre-experimental instructions**
Some participants did not comply with pre-experimental instructions, such as avoiding washing or applying cosmetic products to the sampling area. These participants were then asked to return on another day.
- **Environmental Control**
It was challenging to maintain the climate in the sampling room within specific limits (ambient temperature of 20-22°C and relative humidity of 40-60%). The researcher continuously monitored those parameters and adjusted the ventilation system and humidifier to remain within those ranges.
- **Punctuality of Participants:**
Some participants were late for their scheduled sessions, prolonging the sampling day and complicating data collection. A few participants arrived 30-40 minutes later than expected, extending the sampling day.

4.6 Recommendations for Future Studies

The current study investigated the acute (eight-hour) influence of two ABHR formulations on skin barrier function. Future research should consider the following:

- Investigating the long-term effects of high application frequencies of various ABHR formulations over consecutive days.
- To enhance the generalizability of the findings, include a larger and more diverse sample population encompassing different age groups and skin types.

- Examine environmental factors (e.g. humidity or temperature) and their interaction with ABHRs.
- The effect of seasonal changes and frequent alcohol-based hand rubs (ABHRs) on skin barrier function.

4.7 Recommendations for Alcohol-based hand rubs use

Table 1. Recommendations for the safe use of Alcohol-based hand rubs

This table outlines recommendations for selecting and using ABHR formulations to ensure antimicrobial efficacy while preserving skin health.

Recommendation	Rationale	Reference
Select ABHR products with a minimum alcohol concentration of 60% (v/v)	Ensures effective antimicrobial action against a wide range of pathogens.	WHO (2009), CDC (2020)
Choose ethanol-based hand rubs for better skin tolerability	Ethanol is less likely to cause skin irritation compared to other alcohols like isopropanol.	WHO (2009), Kampf and Kramer (2004)
Choose ABHR formulations that include emollients to prevent skin dryness and irritation.	Emollients help maintain skin hydration and reduce the risk of dermatitis	WHO (2009), Kampf and Kramer (2004)
Avoid ABHR products with allergenic surfactants, colourants, preservatives, or fragrances.	Minimises the risk of skin sensitivity, allergies, or adverse reactions.	CDC (2020), Kampf and Kramer (2004)
Regularly apply moisturisers after hand antisepsis to preserve skin integrity, particularly for dry skin.	It prevents excessive dryness and promotes long-term skin health.	WHO (2009), Larson (1999)
Refrain from using ABHR immediately before or after handwashing to mitigate skin overhydration and irritation.	Excessive hydration from washing increases vulnerability to irritation from ABHR.	WHO (2009), Larson (1999)

4.8 Limitations of the study

The study was limited to short-term (8 hours) experimental exposure to the ABHRs in a controlled environment and focused exclusively on healthy young black females. It did not explore longer-term exposures or ABHR application on variations in skin conditions (pre-existing conditions) and ages, which are significant factors in occupational and real-world settings. Which does not allow the results to be generalised to other racial groups or extend their use over time.

4.9 Conclusion

This study provided valuable insights into the effects of ethanol- and isopropanol-based ABHRs on skin barrier parameters (TEWL, SCH, and SS-pH) over an acute eight-hour period. The findings confirmed that both ABHRs maintained TEWL and SS-pH within healthy ranges, with ABHR1 offering superior hydration benefits and ABHR2 providing a beneficial acidifying effect that supports skin health. These results emphasise the safety and efficacy of these formulations, particularly in professional settings requiring frequent hand hygiene.

The research highlights the importance of designing inclusive, skin-friendly hand hygiene products tailored to diverse populations. While the study addressed a significant knowledge gap, future research should explore long-term effects, including broader demographic groups, and assess environmental factors. By integrating emollient-enriched ABHRs into healthcare protocols, the findings support balancing effective pathogen control with the preservation of skin health, ensuring that hand hygiene practices remain safe and inclusive.

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