SKIN HYDRATION, INJURY PREVALENCE AND FREQUENCY: UNDERSTANDING THE INFLUENCE OF PHYSIOLOGIC, BEHAVIORAL AND DEMOGRAPHIC FACTORS

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This work is dedicated to my loving parents and my very special daughters Makayla Patrice and Leah Nichole Clements.

My late father, Mr. Virgil E. Hunter and my mother, Mrs. Edythe H. Hunter taught me because I am blessed, I am called to be a blessing to others.

To whom much is given, much is required (Luke 12:48).

ABSTRACT

SKIN HYDRATION, INJURY PREVALENCE AND FREQUENCY: UNDERSTANDING THE INFLUENCE OF PHYSIOLOGIC, BEHAVIORAL, AND DEMOGRAPHIC FACTORS

Carla P. Clements

Lea Ann Matura

Skin is the largest and most visible organ of the body. It is the direct interface between the external and internal environment. The skin has compensatory mechanisms to sustain its functions, but external threats may make it susceptible to injury. Although increasing evidence describes the biomechanical properties of the skin, limited clinical studies explore the effects of factors on the skin's outer surface and its susceptibility to injury. Factors associated with skin injury, such as body mass index (BMI), smoking, sun exposure, and age are not always integrated into study designs. This dissertation provided a secondary analysis of pre-existing data (N = 351) from two parent studies describing injury prevalence and frequency in women following consensual sexual intercourse. Data were transferred from the principal investigator of the parent study to this investigator according to human subjects procedures and analyzed using path analysis. Skin hydration was the central focus of the study and is defined as the water content of the stratum corneum. The study showed that both age and BMI were negatively associated with skin hydration, but skin hydration was not a mediator for any of the identified variables, skin color, or viscoelasticity. Additionally, neither the physiologic (BMI), behavioral (smoking and sun exposure) or demographic (age) variables were significantly associated with skin injury prevalence and frequency. Skin color L-value significantly predicted skin injury prevalence, not injury frequency. The results demonstrated that viscoelasticity was not a significant mediator for any relationship between the set predictors and the outcomes of skin

injury prevalence and frequency. Viscoelasticity mediated the relationship between age and skin hydration and age was negatively associated with viscoelasticity. Therefore, although skin hydration did not predict skin injury, skin color (i.e., lightness) predicted skin injury prevalence. Further exploration of all related variables is necessary when identifying patients who are at high risk for skin injury. Future knowledge development can inform multi-level interventions that may target modifiable risk factors to maintain the skin's integrity.

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CHAPTER 1

Skin is the largest, most visible organ of the body and comprises nearly 16% of an individual's total body weight. Independently, the skin typically weighs approximately 18 kilograms (kgs) with the total measurement averaging 1.8 meters^2 and the thickness ranging from 5µm at the facial area to 1 mm on the soles of the feet (Jablonski, 2006; Kottner et al., 2013; Kottner & Surber, 2016; Trojahn et al., 2015). The skin's complex processes promote the overall well-being of the body. The skin's major functions are classified as protective, heat-regulating, secretory, immunological, sensory, and healing (Barbieri et al., 2014; Berardesca & Maibach, 2003; Kozel et al., 2014; Lee et al., 2006).

Table 1

Main Functions of the Skin

Function	Activity
Protection	Skin protects from mechanical and chemical assaults, microorganisms and pathogens, and UV radiation.
Barrier to water loss	Skin prevents the evaporation of excess water and maintains homeostasis of the internal environment.
Temperature regulator	Sweat ducts and blood vessels found in the dermis layer help modulate the body temperature based on environmental conditions.
Detoxification	The body eliminates toxins and harmful inhabitants through the cell desquamation process which occurs in the epidermis.
Immunology (early defense)	Langerhans cells capture and transfer foreign substances to the lymph nodes for removal from the body.
Sensory	Merkel cells, found in the epidermis and nerve endings, enable a sense of touch.
Wound repair	Skin's natural restorative response involves collagen deposition and tissue granulation to repair tissue damage.

Note. Adapted from Barel, A. O., Paye, M., & Maibach, H. I. (Eds.). (2014). Handbook of cosmetic science and technology (4th Ed.) CRC Press

Although all skin functions are vital to the body, protection from external disruption of the skin is necessary to maintain health and wellness. The skin protects the body against physical factors (e.g., shearing forces, mechanical pressure), chemical factors (e.g., solvents, topical medications, burns), and environmental factors (e.g., solar ultraviolet radiation, cigarette smoke) and it supports and protects a state of equilibrium for the body's internal environment (Couturaud, Coutable, & Khaiat, 1995; Lacouture, 2013). Skin biomechanics, including hydration, viscoelasticity, and color, are the biologic, physical and chemical properties that facilitate the skin's protection for the body (Hussain, Limthongkul, & Humphreys, 2013). The skin's complexity and the biomechanical characteristics create an effective defensive line against exogenous factors that threaten homeostasis within the body (Boer et al., 2016).

The entire skin structure is involved in the host defense; however, the top layer, the epidermis works to prevent water loss and loss of other body components to the environment (i.e., inside-outside barrier) and to protect the body from a host of other assaults (i.e., outside-inside barrier; (Baroni et al., 2012). The outermost layer of the epidermis, the stratum corneum (SC), is key to the epidermal functionality. The SC provides an effective and efficient barrier to the penetration of the harmful potential assaults while it serves as the membrane that holds in the body fluids (Eyerich et al., 2018; Murphree, 2017). An intact epidermal barrier helps to ensure that the skin can maintain life-sustaining functions and integrity. Each epidermal layer has a specific role that contributes to ensuring an effective barrier is maintained as noted in Table 2.

Table 2

Layers of the Epidermis

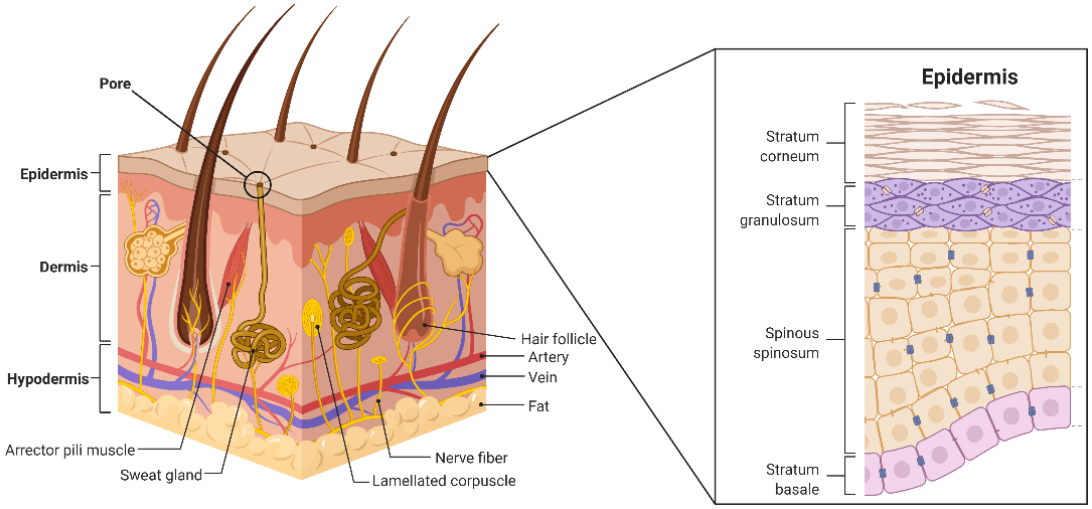
Structure	Description	Activity
Stratum Corneum	Top layer of epidermis 15–20 layers of corneocytes	Dead, anucleated flattened corneocytes. Maintains the moisture balance and protection from the external environment. (Honari & Maibach, 2014).
Stratum Lucidum	3–5 layer of dead, flattened keratinocytes. Cells are tightly compressed, flattened and indistinguishable from one another. Smooth appearance, almost translucent layer.	Cells are found only in the palms, soles, and digits. Densely packed with eleidin, a clear protein rich in lipids; converts to keratin in the SC (Horari & Maibach, 2014).
Stratum Granulosum	Cells are 3–5 layers deep with grainy appearance.	Keratinization begins, cells produce hard granules and as they push upwards, these granules change into keratin and epidermal lipids, keratohyalin is produced. Cells flatten, and membranes thicken (Honari & Maibach, 2014).
Stratum Spinosum	8–10 layers of polyhedral keratinocytes, spiny appearance is due to shrinking of the microfilaments between desmosomes that occurs during laboratory staining.	Keratinization begins, melanin is transferred for UV protection (Honari & Maibach, 2014).
Stratum Basale	Deepest epidermal layer, Merkel and melanocytes produced.	Cells form dermal papillae which increases connection between the dermis and epidermis (Honari & Maibach, 2014).

The epidermal barrier ensures an optimal protective function. The SC and the lipid components within the epidermis are paramount to help maintain the barrier function (Almeida et al., 2022). A decreased barrier function increases the risk of

penetration by pathogens and reduces the skin's capacity for providing protection to the additional layers of the skin and the internal organs (Biniek et al., 2015; Sakai et al., 2005). The properties and condition of the epidermal barrier varies with anatomical location and can be influenced by inherent body-dependent factors, including, skin hydration, elasticity, ethnicity, gender, body weight or even lifestyle habits (A.K. Dąbrowska et al., 2018).

Figure 1

Stratum Corneum Layers



Note. Created with BioRender.com

Skin Integrity

The overall health of the skin is dependent on its integrity. The integrity of the epidermal barrier impacts its functionality (Natsuga, 2014). Skin integrity requires both an intact cutaneous structure and functional capacity that can preserve the actual structure

(Jan Kottner, Beeckman, Vogt, & Blume-Peytavi, 2020). Skin integrity means that the skin is whole, healthy, intact, and can carry out basic processes (Bryant, 2002; Noonan, Quigley, & Curley, 2006). If skin integrity is present, there is substantial protection from the external threats and assaults that may affect homeostasis (Bryant & Rolstad, 2001; J. Kottner & Surber, 2016; Murphree, 2017).

Both intrinsic and extrinsic factors can lead to impairment of the skin's integrity and increase the risk of skin injury. Skin injury is localized trauma or disruption to the skin or the underlying tissue (Baker, Fargo, Shambley-Ebron, & Sommers, 2010; Posthauer, Banks, Dorner, & Schols, 2015; Sommers, 2007). If skin integrity is not present, the skin is susceptible to injury from a spectrum of external and internal factors. Injury to the skin exposes it to microorganisms that are constantly present (Rosenthal, Goldberg, Aiello, Larson, & Foxman, 2011).

The epidermis also contains other components that assist in the skin's functionality. Melanocytes, which provide the skin's pigmentation and protection from UV rays, are found in the epidermis as well as Langerhans cells, part of the immune system. Table 3 provides a general overview of the cells and receptors.

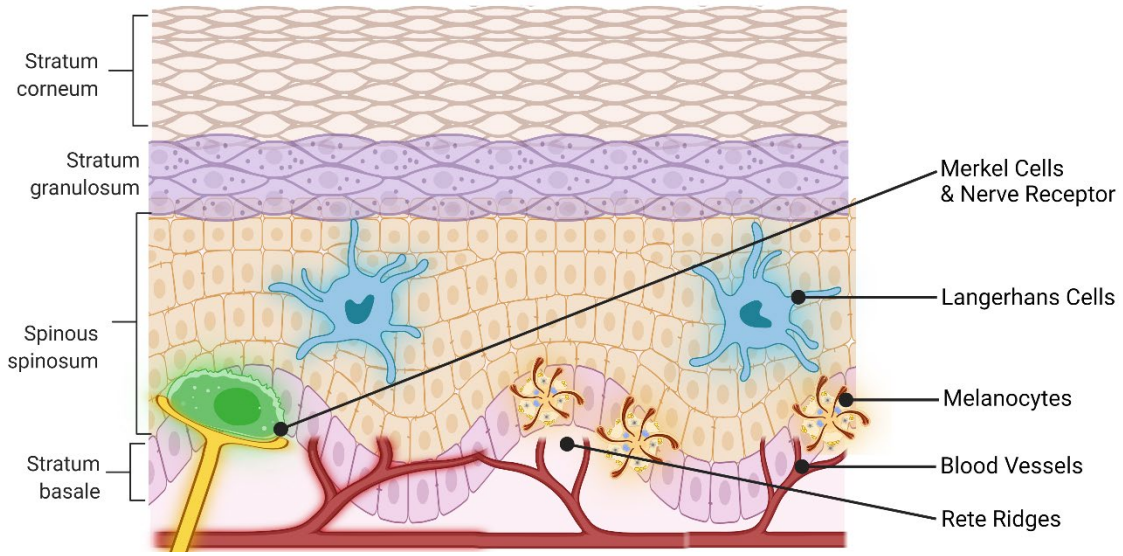
Table 3

Cells and Receptors in the Epidermis

Component	Function	Activity
Blood vessels	Nutrition	Nutrient and oxygenation of epidermal cells from the capillary loops within the papillary dermis.
Langerhans cells	Provides antigens that aid in the skin's immune system	Mainly located within the stratum spinosum and in the papillary dermis.
Melanocytes	Skin pigmentation; Protection from harmful ultraviolet rays	Same number present in both light and dark skin. Melanin pigment produces color variation.
Nerve receptors	Provides sensitivity to temperature, touch, pressure, pain	Largest number of Merkel cells are found on the fingertips.
Rete ridges	Form the dermal-epidermal junction to provide contiguous movement of the dermis and epidermis layers	Borders of epidermis point down and interlock with dermal papillae from dermis. Also called the basement membrane

Figure 2

Skin Cells and Receptors



Note. Created with BioRender.com

In terms of skin integrity, the most notable layer of interest within the epidermis is the SC, where a large proportion of the critical barrier functions of the skin occur (Lee, Jeong, & Ahn, 2006). The state of the SC influences the surface features of skin and the skin's ability to provide vital protection from injury. In healthy skin, the outermost layer of the skin consists of corneocytes surrounded by lipid regions and functions as the main barrier to maintain the integrity (Bouwstra & Ponec, 2006). The lipid organization is a key element for skin's barrier functionality. The three major lipids are ceramides, free fatty acids and cholesterol ((van Smeden, Janssens, Gooris, & Bouwstra, 2014). The anatomy of the skin works in concert with the biomechanical properties. Skin biomechanics are the biologic, physical, and chemical properties that skin in protecting the body (Hussain et al., 2013). The biomechanical properties, including hydration,

viscoelasticity, and skin color, provide protection against environmental assaults and help to preserve skin integrity despite continuous movement, stretching or application of external forces (Clancy, Nilsson, Anderson, & Leahy, 2010; Clarys, Clijsen, Taeymans, & Barel, 2012; Everett & Sommers, 2013; Silver, Freeman, & DeVore, 2001).

Variable of Interest: Skin Hydration

Water plays a key role in the normal physiological balance of the body (Palma 2015), and the biomechanical property, skin hydration, is defined as the water content of the epidermis (Dobrev, 2000). Knowledge of biomechanical factors within the skin are useful in the implementation of preventive actions aimed to restore the epidermal barrier functions and protect against skin injury (Boer et al., 2016).

Approximately 30% of the total weight of skin is water. Specifically, within the epidermis' outermost layer, the SC works to regulate the hydration level of the skin while also controlling the barrier to water loss. The SC is hygroscopic, meaning that it helps skin stay moist and pliable by attracting and holding water (Wissing & Müller, 2003). Adequate hydration is necessary to keep the skin supple, flexible and smooth, which is an ideal condition that enhances skin integrity and supports its barrier.

Significance

The study of skin hydration provides insights into skin integrity and the potential for injury. When skin lacks sufficient hydration, it is more likely to become injured due to a decrease in barrier protection. For example, low hydration levels are prevalent in skin conditions with compromised integrity, such as atopic dermatitis, psoriasis, and eczema (Aubert, Anthoine, Rigal, & Leveque, 1985). Skin surface hydration measurement of the SC is important because the water content influences physical characteristics of the skin,

including the barrier function, mechanical properties, and medication absorption (Baroni et al., 2012; Berardesca, Fideli, Borroni, Rabbiosi, & Maibach, 1990).

As skin science and clinical practice progress, it is important to explore if disorders of skin hydration and its related variables may be associated with either injuries or protective mechanisms. Biomechanical studies on human skin contribute to skin science and advance the areas of injury reduction, protective interventions, surgical progression, and product development (Reihsner, Melling, Pfeiler, & Menzel, 2000).

It is also necessary to identify the potential nature of the assaults, also known as risk factors, and develop targeted strategies and preventative measures to help maintain the skin's integrity (Pancorbo-Hidalgo, Garcia-Fernandez, Lopez-Medina, & Alvarez-Nieto, 2006; Sato, Sanada, Konya, Sugama, & Nakagami, 2006). In 2014, the Spanish Pressure Ulcer Advisory Panel conducted a Delphi Method consensus study based on a structured review of the literature of databases between 1962 and 2009. The review identified and ranked 83 risk factors for skin integrity disruptions that may potentially lead to pressure injury or ulcer. Nutrition, weight, age, UV exposure, and smoking status were ranked as highly significant contributors to skin integrity disruption (García-Fernández, Agreda, Verdú, & Pancorbo-Hidalgo, 2014). Additionally, Emory University's Wound, Ostomy, and Continence Evidence-Based Committee developed an evidenced-based list of recognized risk factors for development of pressure injury (Doughty, 2016).The list included age, decreased level of consciousness, malnutrition, hypotension, increased body temperature, poor vascular perfusion, smoking status, use of vasopressors, and increased immobility (Doughty, 2016).

Both the Spanish Pressure Ulcer Advisory Panel and Emory University's Evidenced-Based Committee suggested several variables that require further inquiry. Attention to these variables would allow clinicians to better understand risk factors for skin injury and to develop interventions that identify or prevent the incidence. It is important to identity factors or variables that may affect skin hydration, and therefore skin integrity, and could increase the risk for injury. Some of the variables of highest importance are age, body mass index (BMI), smoking status, and sun exposure. Although clinical studies have explored the effects of these factors on the skin's outer surface and its susceptibility to skin injury (Aoki & Murase, 2019; Regueira et al., 2019; Schmid-Wendtner & Korting, 2006), few studies have focused on the role of skin hydration with respect to skin injury.

The biomechanical property of skin hydration alone, or in conjunction with other properties such as skin color or viscoelasticity, may influence the prevalence and frequency of skin injury in the presence of variables that may threaten the skin's integrity. It is also important to understand the influence (positive or negative) of factors or combinations of factors and determine their ability to affect injury prevalence or frequency and improve skin health outcomes. Biomechanical properties such as hydration, viscoelasticity, and skin color provide protection against environmental assaults and help to preserve skin integrity despite continuous movement, stretching or application of external forces (Clancy et al., 2010; Clarys et al., 2012; Everett & Sommers, 2013; Silver et al., 2001).

Study Purpose

The purpose of this study was to advance understanding of the factors influencing maintenance of skin integrity, with a focus on the biomechanical property skin hydration. Skin hydration is an important indicator for maintaining an effective barrier function (Rawlings & Harding, 2004b). Physiologic models and previous research suggest that a hydrated SC may provide protection from skin injury (Crowther, Matts, & Kaczvinsky, 2012; Ousey, Cutting, Rogers, & Rippon, 2016). Using the path analysis model, this study tested relationships among the selected variables of age, BMI, smoking status, sun exposure, skin hydration, skin viscoelasticity, and skin color. The study examined if the selected variables had a direct effect on skin injury prevalence and frequency. In addition, the study provided insight into the variability of key endogenous variables, skin hydration, skin viscoelasticity, skin color, and impaired skin integrity, as measured by skin injury prevalence and frequency.

Cross-sectional data collected from two parent studies: "Injury from Sexual Assault: Addressing Health Disparities" (Sommers, PI-RO1NR005352) and "Injury in Latina Women after Sexual Assault: Moving Toward Health Care Equity" (Sommers, PI-R01NR011589) were analyzed to test the relationships among the variables of age, BMI, smoking status, and sun exposure. These variables were chosen because of their relevance to skin integrity based on the literature (Doughty, 2016, Garcia-Fernandez et al., 2014, Regueria et al., 2019; de Farias, 2016, Farage et al., 2008). Skin hydration, skin viscoelasticity, and skin color data were also available from the parent studies and were used to describe the biomechanical function of the skin. To determine skin integrity, data describing injury prevalence and frequency were used.

Study Aims

Aim 1. To determine physiologic, behavioral, and demographic correlates of skin hydration.

Aim 1a. To determine the direct relationship between the physiologic (BMI), behavioral (smoking status, sun exposure) and demographic (age), correlates of skin hydration.

- Hypothesis 1a. There is a direct relationship between BMI, smoking status, sun exposure, age and the correlate hydration.

Aim 1b. To determine the direct relationship of the biomechanical measures (skin viscoelasticity and skin color) with skin hydration.

- Hypothesis 1b. There is a direct relationship between skin viscoelasticity and skin color and the correlate hydration.

Aim 2. To determine whether skin hydration mediates the relationship between physiologic, behavioral, and demographic variables, and skin injury prevalence and frequency.

Aim 2a. To determine whether skin hydration mediates the relationship between BMI, smoking, sun exposure and age with skin injury presence and frequency.

- Hypothesis 2a. Skin hydration will mediate the relationship between BMI, smoking status, sun exposure and age with skin injury prevalence and frequency.

Aim 2b. To determine whether skin hydration mediates the relationship between skin viscoelasticity and skin color with skin injury prevalence and frequency.

- Hypothesis 2b. Skin hydration will mediate the relationship between skin viscoelasticity and skin color with skin injury prevalence and frequency.

Aim 3. To determine physiologic, behavioral, and demographic correlates of skin injury prevalence and frequency.

Aim 3a. To determine the direct relationship between the physiologic (BMI), behavioral (smoking status, sun exposure) and demographic (age,) correlates of skin injury prevalence and frequency.

- Hypothesis 3a. There will be a direct relationship between BMI, smoking status, sun exposure and age to skin injury prevalence and frequency.

Aim 3b. To determine the direct relationship of biomechanical measures (skin viscoelasticity and skin color) with skin injury prevalence and frequency.

- Hypothesis 3b. There will be a direct relationship between skin viscoelasticity, skin color and skin injury prevalence and frequency.

Aim 3c. To determine if skin viscoelasticity mediates the relationship between BMI, sun exposure, smoking status, and age with skin injury prevalence and frequency.

- Hypothesis 3c. Skin viscoelasticity will mediate the relationship between BMI, sun exposure, smoking status, and age with skin injury prevalence and frequency.

Aim 4. To determine physiologic (BMI), behavioral, and demographic (age) correlates of skin viscoelasticity.

Aim 4a. Determine the direct relationship between physiologic (BMI), behavioral (smoking, sun exposure) and demographic (age) correlates of viscoelasticity.

- Hypothesis 4a. There is a direct relationship between BMI, smoking, sun exposure and age and viscoelasticity.

Aim 4b. Determine if skin viscoelasticity mediates the relationship between BMI, smoking, sun exposure and age variables with skin hydration.

Hypothesis 4b. Skin viscoelasticity will mediate the relationship between BMI, smoking, sun exposure and age variables with skin hydration.

CHAPTER 2

Chapter 2 includes a review of the literature regarding skin hydration and skin injury. Additionally, the chapter describes the factors that are related to skin hydration as described in the skin science literature (i.e., BMI, smoking, sun exposure, and age), and the biomechanical properties of the skin (i.e., viscoelasticity and color). Skin biomechanics are properties (biological, physical and chemical) that work with the skin to provide protection to the body (Hussain et al., 2013). Chapter 2 also introduces the conceptual model that guided this research study and addresses the significance and clinical relevance of the study. This secondary analysis fills a gap in the existing literature by examining factors that may influence skin injury and examine whether skin hydration has a protective influence from injury in the presence of the identified factors. If these factors are elucidated, it will impact risk stratification for skin injury in the clinical settings. The long-term goal of this work is to understand and develop interventions that maintain the skin's integrity, promote skin health, and decreases skin injury prevalence and frequency.

Skin Hydration

A series of studies devoted to skin integrity and its barrier protection were conducted during the 1950s (Blank, 1952, 1953). Tape stripping studies provided evidence of the importance of a well-hydrated epithelium as the region responsible for skin barrier function and recovery from injury. Because the SC is the outermost layer, it is the first line of defense against potential intrinsic and extrinsic factors and provides resistance against those threats. Although skin integrity is determined by many factors, the critical biomechanical property of skin hydration influences the integrity of the skin

and provides protection from external injury (Everett & Sommers, 2013; Greenwood & McGinnis, 2016; Held et al., 2015).

The general term hydration refers to the current state of water balance within the body (Benbow, 2006; Clarys et al., 2012). Skin hydration is defined as the water content of the epidermis (Dobrev, 2000).The skin contains over 30% water, but the epidermal water content can be as high as 70% (Y. Choi, Oh, & Lee, 2021; Jan Kottner et al., 2020). It provides a protective function and is an important component of maintaining healthy skin. Sufficient hydration is necessary to keep the skin supple, flexible, and smooth; it enhances skin integrity and supports the barrier function (Pillai, Cornell, & Oresajo, 2010). The amount of hydration within the skin affects many processes including cell signaling, the biomechanical properties, and the skin's actual appearance (Egawa, 2008). It also affects the maturation of epidermal and dermal cells and the desquamation process (Matsui & Amagai, 2015).The SC works to regulate the hydration levels of the skin and controls the barrier to water loss within the epidermis (Verdier-Sevrain & Bonte, 2007). Several past studies demonstrate that the SC water content either directly or indirectly influences the barrier function of the epithelium (Akiyama et al., 2008; Gerhardt, Straessle, Lenz, Spencer, & Derler, 2008; Heinrich et al., 2003).

Stratum Corneum and Skin Hydration

The SC is composed of two components: the corneocytes combined with other substances, including the natural moisturizing factor content (NMF), and the intercellular lipid bilayer matrix (Rawlings & Harding, 2004a). Intercellular lipids are the primary pathway for chemical diffusion and the main barrier to water permeability through the SC layer (Elias, 2005; Nasir, Friedman, & Wang, 2013). Water is essential to all living

organisms and is the single most abundant substance in cells and organisms (Cabral, 2010). Blank (1952) revealed the plasticizing effect of water on the biomechanical properties of the stratum corneum during his tape stripping experiment. As a plasticizer, water provides moisture and enhances the skin's ability to be easily molded or to retain its shape, despite external insults to the skin's integrity. When skin is more hydrated, it is less likely to become injured when exposed to direct harm. For example, the water in both the epidermis and dermis affects other physical properties such as flexibility, pliability, and resistance to shearing forces (Crowther et al., 2012). The water content and physical properties of the SC are interrelated. Compromised skin barriers are frequently correlated with low hydration of the SC (Del Rosso & Levin, 2011; Ousey et al., 2016). Water serves different functions in each layer of the skin. The skin is composed of three layers: the epidermis (the outer layer of the skin, void of any vascularity); the dermis (a highly vascularized layer which provides oxygen and nutrients to the skin via the blood vessels); and the hypodermis (subcutaneous fat layer). The three layers of the skin are interdependent, working together to provide protection and stability for the body. Table 3 gives an overview of the relationships between skin layers and hydration.

Most of the responsibility for the protective barrier function of skin occurs in the SC (Baroni et al., 2012). The water content of the SC primarily determines the appearance, physical properties, and barrier function of the skin (Clarys et al., 2012; Agnieszka K. Dąbrowska et al., 2016; Wilhelm, Elsner, & Maibach, 1991). The SC is a heterogeneous, selectively permeable layer that controls the evaporation loss of body water and protects other vital organs against chemical and physiological environmental assaults (Rawlings, 2010; Rawlings & Harding, 2004a). Barrier function refers to the

natural barrier properties of the SC, specifically in relation to injury protection and tissue repair (Baroni et al., 2012; Elias, 2005).

The SC is composed of 10–15 layers of flat dead keratinocytes. The cells, now considered enucleated corneocytes, are connected by small rivets called corneodesmosomes. Ceramides, free fatty acids, and cholesterol make up the major lipid components of the SC and provide the bulk of moisturization. The intercellular spaces of the SC are filled with a lipid-rich matrix that is arranged to provide a water-proof barrier at the SC level (Mojumdar et al., 2015).The cornified cell envelope (CE) is a ceramide-enriched, lipid envelope that surrounds the corneocytes (Elias, 2012) and provides a vital physical barrier to guard against water loss. The corneocyte cells are embedded in an intercellular matrix that contains nonpolar lipids and is organized as lamellar lipid layers. This arrangement is known as the “brick-and-mortar” structure.

The SC is made up of two components: the corneocytes combined with other substances, including the natural moisturizing factor (NMF) content, proteins, and enzymes, and the intercellular lipid bilayer matrix that work together to provide and maintain moisture (Fujimura et al., 2017; Rawlings & Harding, 2004a). The role of NMF in the SC is to maintain adequate skin hydration. NMF is an efficient humectant that attracts and binds water from the atmosphere and brings it into the corneocytes. Intercellular lipids are the primary pathway for chemical diffusion and the main barrier to water permeability through the SC layer (Lee et al., 2006; Rawlings & Harding, 2004a).

In healthy skin, up to 15% of the SC consists of water (Matsui & Amagai, 2015). A well-hydrated SC is essential for maintaining moisture within the rest of the skin, and for regulating the natural moisture flow from the deeper layers. This flow and the rate of

water vapor loss from the body is known as trans epidermal water loss (TEWL); a higher TEWL is equated with decreased skin hydration (Clarys et al., 2012). Adequate hydration of the SC serves four main functions as a barrier. It maintains the plasticity of the skin, protects it from damage, allows hydrolytic enzymes to function, and facilitates the desquamation process (Rawlings, 2010). The water balance of the SC is dependent on three major mechanisms: the intercellular lamellar lipids, which provide a tight and effective barrier; the presence of matured corneocytes, which influence the diffusion path of the water passing through; and the presence of NMF (Elias, 2005; Rawlings & Harding, 2004a). If there are major disturbances in any of the three areas, an ongoing cycle of events occurs, which can lead to an inferior SC and an overall decrease in hydration.

Changes in skin hydration can modify other mechanical properties of the skin, such as permeability and cell cohesion (Biniek, Kaczvinsky, Matts, & Dauskardt, 2015). The changes can occur because of abnormal cell proliferation and differentiation, abnormal lipid and protein synthesis, or modification of corneocyte desquamation (Honari & Maibach, 2014; Matsui & Amagai, 2015; Rippke, Schreiner, & Schwanitz, 2002). In several studies, abnormal SC hydration, either elevated or diminished, reduced skin resistance and caused the skin to be more vulnerable to injury or infection (J. W. Choi, Kwon, Huh, Park, & Youn, 2013; Proksch & Brasch, 2012). When the hydration level of the SC contains less than 10% water, many of the normal processes may be impeded, with decreased function. This study will extend previous skin science research by building upon existing knowledge aimed at developing interventions to promote skin health and the maintenance of skin integrity.

Individual Risk Factors for Skin Injury

Age

By the year 2050, the population of individuals who are 65 years of age and older will nearly double (Biniek et al., 2015). Promotion and maintenance of skin integrity in the clinical setting is one of the most common problems, especially in the elderly population. Aging skin is thinner and shows specific changes to the epidermis that includes a flattening of the interface between the skin layers (J. W. Choi et al., 2013). Many laboratory and clinical trials have focused on aging skin which undergoes progressive and degenerative changes (Biniek et al., 2015; Chang, Wong, Endo, & Norman, 2013). The additive effect of the aging process on skin hydration results in a less effective barrier, increased risk of infection, and more threats to skin integrity.

Aging seems to influence other demographic factors as well. Hydration and skin pH decrease with age (Dayan, 2008; Mattar, 2011; Pawlaczyk, Lelonkiewicz, & Wieczorowski, 2013). Epidermal irritability and sensitivity increase with age, and in turn, makes the skin more prone to integrity disruption (Hess, 2013; Mattar, 2011). An extensive systemic review built upon existing knowledge and provided evidence-based synthesis of basic skin care interventions for the aged patient (J. Kottner, Lichterfeld, & Blume-Peytavi, 2013). The influences of skin viscoelasticity, aging, and hydration were investigated, and the results confirmed previous findings that both hydration and elastic recovery decrease with age. Additionally, higher skin hysteresis values correlated with more wrinkle formation (Trojahn, Dobos, Blume-Peytavi, & Kottner, 2015). Several studies have found that skin barrier function decreased with chronological aging but

varied per anatomical location for the populations studied (Garcia & Thomas, 2006; Pappas, Fantasia, & Chen, 2013; Pawlaczyk et al., 2013).

BMI

The World Health Organization (WHO,2016) defines BMI as the ratio of body weight to the square of body height. The internationally accepted values are expressed in units of kg/m^2 and provide a standardized marker for malnutrition, normal weight, and obesity (VanGilder et al., 2009). Baseline nutritional status and BMI plays a significant role in tissue viability and protection from injury. However, it is not clear if lower BMI or a higher BMI provides the protection. Study results are conflicting and often inconclusive.

The literature does show that there is increased risk for pressure injury in the obese and in malnourished patients (Beitz, 2014; Compher et al., 2007). In a retrospective analysis, high body mass was found to be a strong predictor of intraoperative acquired pressure injuries in patients during spinal surgery P=.0016. odds ratio [OR] 1.22,95% (CI) 1.08-1.4)(Yoshimura et al., 2020). Results from one study suggest that dry skin and a high TEWL, which equates to low hydration, in the obese group may lead to epidermal barrier changes and increased risk for pressure injury when compared to their control group (Loffler et al., 2002). Several studies suggested that a low BMI is associated with a higher prevalence of pressure injuries, and higher BMI scores may have a protective effect (Choo et al., 2010; Compher et al., 2007; Drake et al., 2010). Studies that have predicted BMI in hospital acquired pressure injury found BMI had a U-shape relationship, meaning the likelihood of a pressure injury increased in patients with the lowest and highest BMI values (Kayser et al, 2019).

Both increased and decreased BMI are related to alterations in skin integrity. In a study of intensive care unit patients, the investigators found that the incidence of pressure injury in the underweight, normal weight, obese, and extremely obese groups was 8.6%, 5.5%, 2.8%, and 9.9%, respectively (Hyun et al., 2014). While both the scores on the Braden scale and the BMI were predictive of pressure injuries, extremely obese patients were about 2 times more likely to experience an ulcer than were normal weight patients. BMI and recent weight loss each may affect skin viscoelasticity, due in part to the changing thickness of hypodermal adipose tissue, which functions as a structural foundation to the skin. Increased hypodermal support from adipose tissue may provide increased resilience while decreased adipose tissue may increase risk of injury (Bosy-Westphal & Muller, 2015; VanGilder, MacFarlane, Meyer, & Lachenbruch, 2009).

Results from the 2006–2007 pressure injury prevalence survey were analyzed to assess the relationships among pressure injury prevalence, BMI, and weight. The survey measured a total of 702 facilities which included acute, rehab, and long-term care with a combined number of 68, 964 patients in 2006 and 58,160 in 2007. The median weight of participants was 167 pounds. The overall pressure injury prevalence was highest in patients with a BMI in the underweight category approximately 25%, ($p < .001$) compared to the other BMI categories. Patients with a normal BMI had a higher overall prevalence of pressure injury than overweight and obese BMI categories as well ($p < 0.001$). Findings indicated that there was a higher prevalence of pressure injuries in patients with low BMI and in patients with both low and normal weights (VanGilder et al., 2009). However, another research group found that a BMI greater than 40 (indicating morbid obesity), was associated with an increased disruption of skin integrity, increased

skin hydration, and a higher risk for pressure injury development (Drake et al., 2010). Mildly increased BMI may act as a protective mechanism (Compher, Kinosian, Ratcliffe, & Baumgarten, 2007). But this effect is lost when the BMI is so high that it negatively influences mobility, exposure to moisture, and impairs other skin care interventions (Drake et al., 2010). During the literature search, however, no research was found that directly examined the role of skin hydration as a protector from injury.

Smoking

Skin that ages prematurely commonly occur among people who smoke tobacco products (Ortiz & Grando, 2012). As the most external layer of the skin, the SC is directly exposed to tobacco smoke and most susceptible to the oxidative damage that occurs with tobacco use. Exposure to cigarette smoke stimulates increased production of free radicals, impairs synthesis of cholesterol, and jeopardizes skin barrier function (Knuutinen et al., 2002; Trojanová et al., 2011; Xin et al., 2016). Direct contact with cigarette smoke reduces hydration levels in the SC and induces a mild inflammatory response, which negatively impacts skin integrity. Tobacco smoke also alters the function of the fibroblasts of the skin and decreases biosynthesis of type I and III collagens, causing disruption of the connective tissue of the extracellular matrix (ECM), and reducing the skin's viscoelasticity (Raduan et al., 2008). A cross-sectional study was conducted in Brazil to evaluate the association between smoking and cutaneous aging. After controlling for many variables such as sex, sunscreen use, and coffee intake, the research found that age, chronic sun exposure, skin photo type, and tobacco load significantly contributed to the formation of facial wrinkles, and a higher tobacco load correlated with an increased number of facial wrinkles (Raduan et al., 2008). When

evaluating differences in the moisture content directly in women across age groups, researchers found that hydration levels and lipid content was significantly lower in women smoking between 11 to 20 cigarettes daily, irrespective of age (Wolf et al., 1992).

Sun Exposure

Overexposure to the sun's rays, both visible and invisible, can be harmful to all skin layers. Damage can be immediate or long-term. Immediate damage manifests as erythema and sunburn, which causes cell tissue degradation and disrupts the skin's integrity (Mizuno et al., 2016; Wan et al., 2017) Ultraviolet exposure (UV) from the sun speeds up the aging process by disrupting the normal architecture of the connective tissue within the dermis. UV light decreases collagen and elastin and alters the cross-linked structure of the collagen and elastin fibers within the extracellular matrix (Knuutinen et al., 2002; Pillet, Gibot, Madi, Rols, & Dague, 2017). Excessive exposure effects the hydration of the skin by damaging the lipid content with free radicals. The participants in the three studies mentioned all showed similar results; the sun affected the lipids within the SC and the aging process.

Age affects the amount of damage due to sun exposure. Liu et al. (2012) assessed SC hydration levels for sun exposed males and females versus non-sun exposed participants who were matched according to age groups (19–75 years). Results showed SC hydration levels were no different in sun exposed versus non-sun exposed in the young group (19–45 years) for either male or females. However, in the older group (≥ 45 years), a statistically significant difference was found between females and males. Females experienced lower hydration levels at sun exposed areas (Liu et al., 2012).

In another study, researchers assessed the visual impact of repeated UV exposure (Mac-Mary et al., 2010). Eight women and two men presented with asymmetrical signs of photo aging due to overexposure of one side of their face to the sun through a window. Significant differences were observed on the exposed side of the face versus the unexposed side. Clinical scores for wrinkles, skin roughness on the cheek, and skin heterogeneity on the cheekbone were higher on the exposed side. Women tended to show more visible signs of aging and decreased skin hydration, regardless of sun exposure. Sun exposure and aging appear to have additive effects on the skin's integrity, which may increase susceptibility to injury. Thus far, no studies have been found to test whether increased hydration decreases the skin's susceptibility to injury in the presence of increased UV exposure.

Biomechanical Properties of Skin

Skin Viscoelasticity

Skin elasticity (SE) is an important individual, gender, and age dependent property. A primary function of the skin is to protect the internal organs and tissues from mechanical trauma. The dermis is the layer mainly responsible for protecting the body against mechanical injury. In general, elasticity is the ability of a substance to change its length, volume or shape when a force occurs and return to its original form after the force has been removed (Clancy et., 2010). Viscosity is the amount of a fluid's resistance to flow when force or stress is applied to the fluid (Regueira et al., 2019). Skin viscoelasticity (SVE) is the ability of the skin to stretch under tension and return to its original state (Everett & Sommers, 2012). Because the skin is viscoelastic, the mechanical response to a stimulus involves both a viscous component associated with

energy dissipation, and an elastic component associated with energy storage (Christensen et al., 1977; Silver et al., 2001). The energy from an external insult is partially dissipated because the viscous sliding of the collagen fibers and the elastic component allows the skin to return to its original state (Dobke et al., 2002; Saulis et al., 2002). The three major extracellular components of the dermis are mainly responsible for skin elasticity: collagen, elastin, and hyaluronic acid (Yang et al., 2003). Skin hydration and viscoelasticity work together to maintain skin integrity. An increase in skin hydration and lipid content within the SC improves the viscous resistance against deformation (Wissing & Müller, 2003), demonstrating that skin viscoelasticity is affected by hydration levels as well. Another study found that fluidity was the most sensitive variable for epidermal water content. As hydration levels increased in both the epidermal and dermal layers, more dermal interstitial fluid loosened the connections between the fibers, making the tissue less vicious and more fluid-like (Dobrev, 2017). The group concluded that hydration is vital to ensuring the viscoelastic protection, which is essential for injury protection. The viscoelastic behavior of human skin under pressure was investigated (Dayan, 2008). The results showed the viscoelasticity was directly related to the dermis layer.

Constitutive Skin Color

Human skin color is a combination of absorption, reflection, and light scattering as it strikes the skin's surface (Andersen & Maibach, 1979; Sommers et al., 2013; Taylor & Cook-Bolden, 2002). Constitutive skin color (i.e., the natural, genetically determined color of the skin) results from unpigmented skin color mixed with colors of various pigments such as melanin, hemoglobin, and carotene. In 1974, Weigand et al.

demonstrated that the SC of people with black skin contained more cell layers than the SC of people with white skin, through the process of cellophane tape stripping (Weigand et al., 1974). Increased cell layers provide darker skin with a more compact SC and creates greater cohesion between the cells, which has been interpreted as a stronger skin barrier (Mahe, 2002). Interracial differences in skin permeability as noted by TEWL have repeatedly been found, with Whites having the lowest TEWL, followed by Asians and then Blacks (Anderson & Cassidy, 1973; Berardesca & Maibach, 1996). However, researchers do not have a thorough understanding of the role of skin color with respect to skin integrity.

Skin color plays a distinct role in the detection of and protection from skin injury in a variety of contexts such as sexual assault, birth trauma, and pressure ulcer formation (Anderson et al., 2008). For example, in several studies led by Sommers, the investigators found that in a sample of predominantly Black and White females, there were significant differences in ano-genital injury prevalence between the two groups after consensual sexual intercourse and sexual assault (i.e., nonconsensual intercourse). They found a significant association between race (Black versus White) and genital injury (AOR, 4.30; 95% CI, 1.09–25.98; P = 0.03), indicating that the odds for genital injury among Whites was more than 4 times greater than among Blacks (Sommers, Zink, & Baker, 2006).. Importantly, in one of these studies, the differences in injury prevalence were more fully explained by skin color than by race/ethnicity (Sommers et al., 2006). The initial regression model also found similar results when looking at race/ethnicity Model 1 (AOR 3.13; 95%CI, 1.38-7.44; P = .0073), but when skin color was added to Model 2, the numbers changed significantly for race/ethnicity (AOR 1.14; 95% CI, 0.31-8.81; P =

0.842). Based on these results, skin color, not race/ethnicity, seems to be a biomechanical property of skin that is related to skin injury. It is critical to include skin color as a variable to study in future models, as researchers seek to understand more about skin integrity. Past research exploring these factors mainly involved participants with light skin, and demographic data primarily reflecting that these patients identified as White. Thus, most models that have been developed are based on what is known about people with light skin color, and do not reflect all populations. The United States (U.S.) Census Bureau projects that by the year 2050, over 60% of the U.S. population will have a skin color that likely will not be considered White (He et al., 2016). As the population shifts in color, there is an increasing onus on healthcare workers to develop evidence-based strategies to maintain and improve skin health that will potentially reduce risks to skin integrity. Hence, more research is needed for targeted interventions to promote skin integrity.

Injury Identification at the External Genitalia

The prevalence and frequency of tears and abrasions at the external genitalia will serve as a proxy for skin injury in this secondary analysis. In the parent study, the external genitalia were defined as the labia majora, labia minora, periureteral area, posterior fourchette, fossa naricularis, and perineum and anus. The anatomical areas are also collectively known as the vulva region (Farage, 2005). At the cellular level, large surface areas of the external genitalia area are comparable in structure to other areas of the body's exposed skin (Farage & Maibach, 2006). The cutaneous epithelia of the vulva and skin from several anatomic sites, including the inner thigh, back, and forearm, are all embryonically derived from ectoderm and are composed of keratinized stratified

squamous cells with hair follicles, sebaceous, and sweat glands The skin thickness is higher at the labia majora and perineum but decreases from the outer to inner surface toward the labia minora and the inner genital structures (Deliveliotou & Cretsas, 2006; Elsner et al., 1990). In general, the SC of vulvar skin is thinner than other non-exposed skin.

The relative permeability of vulvar skin is influenced by its elevated hydration and reduced water barrier function, due to lipid composition and epithelial structures (Farage & Maibach, 2004). Comparison of properties including permeability, barrier function, and irritant reactivity of the external genitalia and exposed skin has been studied in several populations. In 1991, a small study examined the local reaction to low-concentration sodium lauryl sulfate (SLS). Reactivity was studied in 20 healthy women (10 premenopausal and 10 postmenopausal). Skin changes were monitored by measuring TEWL, SC hydration, and by visual scoring (VS). On the forearm, the premenopausal women experienced significantly more irritation, as noted by greater increase in the VS and TEWL, than the postmenopausal women. In vulvar skin, the only significant differences were in hydration measurements. The researchers found lower hydration levels in postmenopausal women than in premenopausal women (Elsner et al., 1991).

In other comparison studies, the moisture content of vulvar skin measured by capacitance is reported to be equal to or only slightly higher than that of forearm skin (Wilhelm et al., 1991). The group also reported no difference between the capacitance (skin moisture) skin at the forearm, vulvar skin, or skin at the inner thigh. However, another study comparing TEWL levels, which is also an indicator of barrier function, in the vulvar and inner thigh skin found conflicting results. The researchers assessed 58

premenopausal women between 18–35 years old. The study found significant differences in skin surface water for the thigh and the vulva. TEWL at the inner thigh area is usually lower than the vulva region (Warren et al., 2005). Although not completely equivalent, based on the literature review, the prevalence and frequency of skin tears and skin abrasions at the external genitalia during the initial examination of the parent study is a sufficient proxy for skin injury in this secondary analysis with understood limitations.

Conceptual Models of Skin Integrity and Skin Injury

For several decades, maintaining skin integrity has been a surrogate term for pressure ulcer/injury prevention in the nursing literature (Bergman-Evans et al., 1994; Szewczyk et al., 2006). However, a recent systematic literature review revealed that an increased number of manuscripts focused on other types of skin injury caused by a disruption of skin integrity. Injuries included incontinence-associated dermatitis, skin tears, skin abrasions, and medical adhesive-related skin injury (Campbell et al., 2016). Injury is a public health concern, but this phenomenon is not well studied by nurse scientists (Sommers, 2006). Sommers proposed a roadmap for scholarly inquiry on injury that involves four physiologically based strategies: risk identification; development to explain the risk behavior and injury; identification of interventions to prevent and control the injury; and the creation and refinement of culturally relevant interventions. This physiological, theoretical model of skin hydration (see Figure 3), was developed to better understand the influence and relationship of individual risk factors (e.g., age, BMI, smoking, sun exposure) and the biomechanical properties of skin hydration, skin elasticity and constitutive skin color, on skin injury prevalence and frequency. This model illustrates the conceptual relationships between skin injury, skin hydration, and

other important biomechanical properties that are critical to skin health (e.g., constitutive skin color and viscoelasticity). In addition, the model examines individual physiologic factor (i.e., BMI), behavioral factors (i.e., smoking and sun exposure) and demographic factor (i.e., age), that may influence skin integrity. The model is a theoretical construct based on an extensive review of the literature and is based on what is understood about the physiology of skin biomechanics and skin injury. The model allows for adaptability to test for relationships among the identified variables. The 2 models shown (Figures 3 and 4) are an illustration of the theoretical direct relationship and the theoretical relationships with hydration as a mediator.

Figure 3

Conceptual Model of Direct Relationships

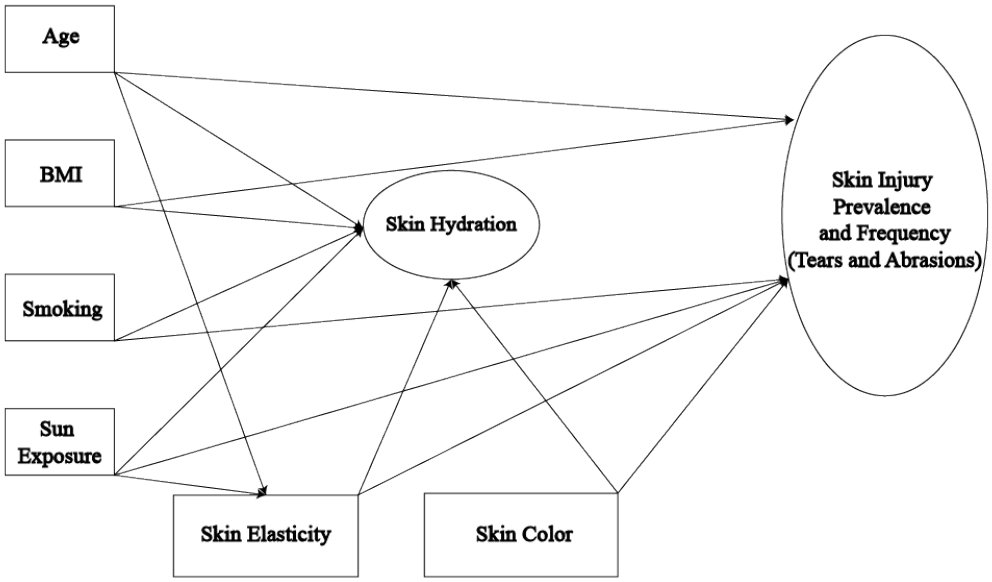
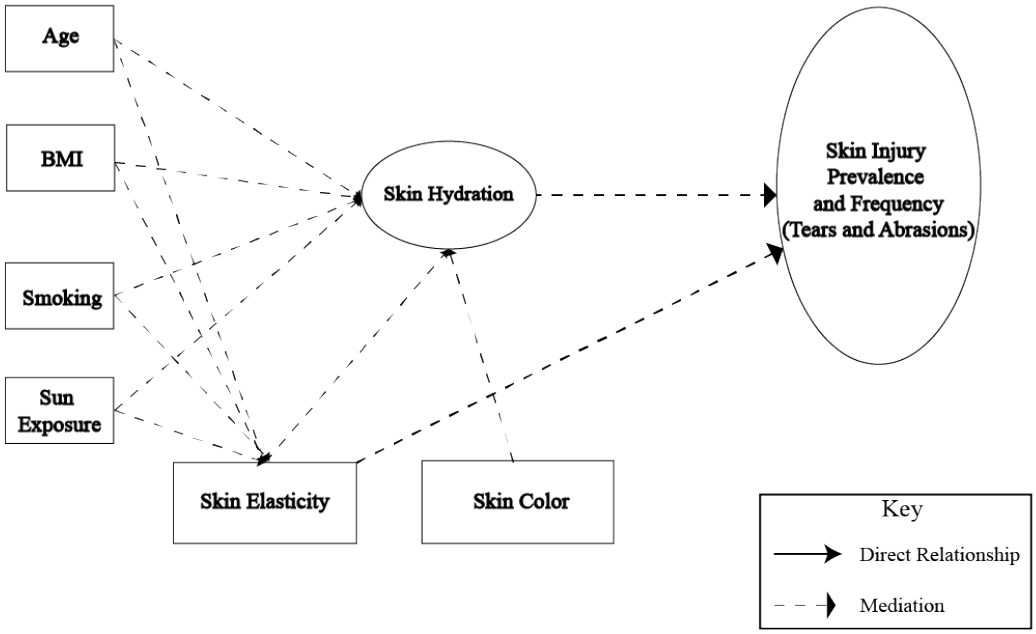


Figure 4

Conceptual Model of Mediated Relationships



Significance of Skin Injury

Dermatological diseases are common and affect approximately 50% of people worldwide at any given time (Lacouture, 2013). Skin injuries can cause pain, decrease self-esteem by disfigurement or disability, and contribute to feelings of isolation. Additionally, mortality rates directly related to skin integrity disruptions have steadily increased despite aggressive education and public health awareness initiatives (Bryant, 2002; Bryant & Rolstad, 2001). Caring for patients and recognizing potential threats to their skin integrity while detecting other physiological changes to prevent potential complications is central to the role of the registered nurse (RN). On average, 15–20% of daily nursing care is devoted to tasks related to support or maintain the skin's integrity in

the acute, long-term, and home care settings (Kottner & Surber, 2016; MacLeod et al., 2002). Nursing tasks can range from basic skin care hygiene to providing physical support based on established risk assessments and protocols. It is important to understand how external factors affect the skin's integrity. It is equally important to understand the influence (either positive or negative) of individual or combinations of biomechanical properties on the skin's integrity, and whether these properties provide protection from potential skin injury.

RNs function as a surveillance system within a practice environment. The better the quality of care of the environment, the more fully the RN can perform surveillance, resulting in improved outcomes (Clarke & Aiken, 2003). Improving the environment includes providing the nurses with tangible tools (e.g., skin products or assistive devices) and/or intangible tools (e.g., evidenced and researched based knowledge). Nurses and other caregivers play a pivotal role in skin health, and implement interventions to maintain skin integrity and reduce the potential for environmental threats to the skin (Miller, 1995; Penzer & Ersser, 2010). Providers should recognize risk factors for potential skin injury and understand biomechanical factors that may reduce the risk for disruption of skin integrity and provide protection from injury.

One of the common challenges facing nurses in any healthcare setting is the promotion and maintenance of skin integrity. Alteration in skin integrity affects patients across the life span, in both outpatient and inpatient settings (Noonan et al., 2006). When the integrity barrier is breached, skin is more susceptible to diseases ranging from xerosis (dry skin) to psoriasis, to stage 4 pressure ulcers and pressure-related injuries.

Since 1994, the American Nurses Association (ANA) has identified the maintenance of skin integrity as a clinical indicator to evaluate the quality-of-care delivery for in-patient acute settings (Lyder et al., 2010). Per the NANDA, North American Nursing Diagnosis Association group, skin integrity risk is defined as a patient being at risk for alteration in epidermis and/or dermis (Lyder, Krasner, & Ayello, 2010). The diagnosis is classified in the domain of patient safety and represents a continued concerned for all members of the healthcare system. Lack of skin integrity and the resultant incidence of pressure ulcer development and other cutaneous disorders are nurse-sensitive patient outcomes (Savitz et al., 2005). The influence of hydration on various factors for protection of skin injury and integrity is relevant to nurses as direct and indirect care providers.

Skin Injury and Nursing Science

The WHO defines injury as the physical damage that results when the human body is suddenly or briefly subjected to intolerable levels of injury (Holder et al., 2001). Epidermal injury is localized damage to the outer layer of the skin. The phenomenon of injury, regardless of the definition or classification, is a fertile area of nursing inquiry (Sommers et al., 2006). In 2016, the National Pressure Ulcer Advisory Panel (NPUAP) consensus group of experts made sweeping recommendations to revise the term from pressure ulcer to pressure injury (National Pressure Ulcer Advisory Panel, 2016). This nomenclature change has been endorsed by the Wound, Ostomy, and Continence Nurse (WOCN) Society and is reflected in the WOCN guidelines for pressure ulcers or injuries. This change is considered a drastic move within the expert community and has been met with uncertainty and some resistance. However, this proposed change is a step toward

recognition of the complex interplay involving disruption of skin integrity influenced by epidermal injury. Nurses are uniquely situated within the healthcare environment to increase understanding of injury science and its consequences. Much of the literature prior to the change of terms refers to a disruption and injury to the barrier function of the skin as a pressure ulcer (Bergman-Evans et al., 1994; Mehta et al., 2015; Scheel-Sailer et al., 2016). For the purposes of this dissertation, the term pressure injury was defined as damage to an area of the skin caused by constant force and leads to a disruption of the skin integrity.

Pressure injury development is a serious quality of care and patient safety issue (Everett & Sommers, 2013; Zaratkiewicz et al., 2010). These injuries occur in over one million patients annually (Borzdynski et al., 2016). In 2003, the Hospital Cost and Utilization Project (HCUP) reported 455,000 hospital-acquired pressure ulcers (HAPU) during acute hospital visits, a 63% increase from 5 years earlier (Brem et al., 2010). Additionally, pressure injuries cost $9.1–$11.6 billion per year in the U.S. (Quality, 2014) In 2007, Medicare estimated that each pressure injury added $43,180 in costs to a hospital stay (Quality, 2014). Approximately 26% of acute care patients will acquire or enter the hospital with a pressure injury, and the cost of individual care can range from $20,900 to $151,700 per ulcer, depending on the stage (Amlung et al., 2001; Chan et al., 2013).

Despite continual public health awareness campaigns and education funding for pressure injury prevention, the numbers for HAPU continue to stay constant or, in some regions, rise (Zaratkiewicz et al., 2010). A more recent nationwide study aimed to evaluate the impact of pressure injuries on short-term outcomes of U.S. in-patient

populations and to identify patient characteristics associated with having one or more pressure ulcers. The results revealed concerning data (Health, Research & Educational Trust, 2016). The study compared in-patients with at least one pressure injury to a control group of in-patients with no pressure injury, using the U.S. Nationwide Inpatient Sample (NIS) database. The 5-year average number of admitted patients with at least one pressure injury increased from 670 to 767 (average overall rate: 1.8%). Statistically significant differences between patients with and without pressure injuries were observed for median length of stay (7 days [mean 11.1 ± 15] compared to 3 days [mean 4.6 ± 6.8]) and median total hospital cost ($36,500 [mean $72,000 ± $122,900] compared to $17,200 [mean $32,200 ± $57,500]). The mortality rate in patients with a pressure injury was significantly higher than in patients without a pressure ulcer (9.1% versus 1.8%, OR = 5.08, CI: 5.03-5.1, P <0.001) (Trust, 2016).

Skin injuries which result from disruptions in skin integrity are a significant issue across all healthcare settings. Identification of risk factors and developing effective strategies to help prevent injury will improve the quality of care across various populations.

To date, we have found no studies or investigators who have examined demographic and lifestyle factors (i.e., age, BMI, smoking, and sun exposure), and biomechanical factors (i.e., skin color and skin elasticity) as they relate to how skin hydration plays a protective role against injury. This secondary analysis proposes to address the gaps in the literature by determining: (a) physiologic, behavioral, and demographic correlates of skin hydration; (b) whether skin hydration mediates the relationship between physiologic, behavioral and demographic, variables and skin injury

prevalence and frequency; (c) physiologic, behavioral and correlates of skin injury prevalence and frequency and (d) determine the demographic, behavioral, and physiologic correlates of skin viscoelasticity.

Summary

The skin is the largest and one of the most complex organs of the body. It acts as a two-way barrier that prevents loss of water and other internal body components to the environment (inside-outside barrier) and protects the body from environmental insults (outside-inside barrier). The skin works at full capacity if the epidermal barrier remains intact and skin integrity is maintained. The outermost layer of the epidermis, the SC, consists mainly of protein-enriched cells and intercellular lipids, and is chiefly responsible for maintaining skin's integrity. Epidermal injury is localized damage to the outer layer of skin. Skin hydration is a critical biomechanical property that may influence the protective barrier against injury. Despite this significance, the protective role of biomechanical properties or conceptual discussions of injury have been nearly absent in the nursing literature (Everett & Sommers, 2013). This secondary analysis focused on the protective functions of the skin and identified factors from the parent study that may influence the skin's ability to carry out healthy functions.

CHAPTER 3

This chapter explains the design of the study and the methodology of data collection and analysis. This dissertation study was a secondary analysis that used cross-sectional data collected from the two parent studies: "Injury from Sexual Assault: Addressing Health Disparities" (Sommers, PI-RO1NR005352) and "Injury in Latina Women after Sexual Assault: Moving Toward Health Care Equity" (R01NR011589) to meet the study aims. The parent studies were led by Sommers and her research team at the University of Pennsylvania and the University of Puerto Rico Schools of Nursing. The study population was a sample of women 21–65 years of age from both Philadelphia, Pennsylvania and San Juan, Puerto

Parent Studies

The two parent studies used a two-group (control versus survivor), comparative design to study ano-genital injuries that occurred in women resulting from consensual and nonconsensual intercourse.

The parent studies had three aims:

- To use three forensic examination techniques (i.e., unaided visual inspection, inspection with a colposcope including digital image capture, and contrast with toluidine blue including digital image capture) to identify ano-genital injuries from two conditions: following consensual sexual intercourse and sexual assault in Black, White, and Latina women, and in women of other ethnicities.

- To quantify skin color (L*=light-dark values, a*=red-green values, b*=yellow-blue values, melanin index) in prospective samples of women following consensual sexual intercourse and sexual assault through spectrophotometry (consensual only) and digital image analysis (consensual and sexual assault) in Black, White, and Latina women.
- To investigate the relationship between variation in skin mechanics (skin elasticity and skin hydration) and other factors (skin color, age, body mass index (BMI), total body water, body composition (fat mass and fat-free mass), estrogen level, sun exposure, and health status) on ano-genital injury prevalence and frequency after consensual sexual intercourse in Black, White, Latina, and women of other ethnicities.

The participants completed a data health questionnaire and pregnancy test, and underwent skin measurements of skin elasticity, skin hydration, skin color, BMI, and body composition. A baseline forensic gynecological examination which included ano-genital injury identification was conducted. After consensual intercourse with a male partner, the participant returned for a second forensic gynecologic examination for genital skin injury identification.

Recruitment for the Parent Studies

Philadelphia participants were recruited from primary care practices; the University of Pennsylvania campus, surrounding urban areas in Philadelphia through churches, YWCAs, and women's groups and from the victims' service agencies. In San Juan, participants were recruited through the University of San Juan, victim's advocacy agencies, and San Juan Memorial Hospital. The recruitment was accomplished by word

of mouth, verbal discussions and with carefully worded signs and flyers which were placed in women's rest rooms and various public waiting areas.

Inclusion Criteria

The following criteria were the characteristics necessary for participant inclusion in the study:

- A signed informed consent form.
- Females aged 21 years or more.
- Voluntary participation in an interview, sexual history, and two colposcopy examinations, baseline and following sexual intercourse with a male.
- Willingness to allow research study personnel to contact their partners for informed consent.
- Willingness to have their partners be contacted by research study personnel to verify that consensual intercourse had occurred.

Exclusion Criteria

- Injury to the genitalia in the last month (as pre-existing injury may change the injury findings after consensual sex).
- Pregnancy-to avoid the risk of complications which may occur as a result of the pelvic examinations.
- Menses at the time of enrollment. Injury visibility can be more difficult if data collection occurs during the time of heaviest flow.
- Allergies to contrast media; participants with allergies to contrast media were excluded because of the application of toluidine blue.

- Refusal to approve partner notification or fear that partner notification will lead to the potential for intimate partner violence.

Potential Risks

Pregnancy, Abnormal Findings, or Sexually Transmitted Infections

Participants completed a urine pregnancy test prior to the baseline forensic exam. After completing the baseline forensic exam and digital images, the nurse examiner gave participants the results of the wet prep. If the results from the wet prep or Trichomonas Rapid Test were abnormal, treatment options were discussed with the participant. Participants were encouraged to see their primary provider, but they were also given the option to seek care with co-investigators and women's health practitioners. If a referral was recommended, the study team referred the participants to the Philadelphia or San Juan Health Department or a primary care practitioner of their choice. The same procedure was followed if any abnormal findings were identified during the colposcopy portion of the forensic examination.

Emotional Distress

Because the researchers wanted to ensure that no participant was uncomfortable psychologically or physically during the examination, the examiner asked the participant several times during the procedure if the participant wished to continue. The participant was aware that they could stop the exam whenever they felt uncomfortable. During the forensic exams for the consensual group, the only study staff present were a nurse examiner and female study staff such as student workers, the principal investigator, or the

project manager, and on occasion other select members of the research team and consultants who monitored the stability of the examination procedures across participants. All participants received full payment of $300.00 for participation once the examination began, even if they declined to complete the examination once it was started. The parent study researchers had no requests to halt the examination because of physical or psychological discomfort.

Physical Injury from Exam Procedures

The procedures required for the forensic examination placed the participants at risk for injury and complications comparable to a standard gynecologic examination. Those injuries include minor skin injury from speculum insertion and minor discomfort during the exam.

Intimate Partner Violence

The participant's partner was not allowed to be present during the exam, but the partner was able to wait in the lobby of Fagin Hall or the Clinical Research Center in San Juan during the examination, where a security guard was always present.

Skin Irritation from the Non-Invasive Measures of Skin Mechanics

Minor risks for a topical allergic reaction from toluidine blue application also existed. All participants who had allergies to contrast media were excluded. If a local reaction occurred (skin irritation is an uncommon but possible adverse event), the participant was referred to a women's health nurse practitioner. There was minimal risk of skin irritation from use of the devices for non-invasive measures to skin color, elasticity, and hydration. All devices were applied to the external surface of the skin using either gentle pressure or gentle suction. There was minimal risk of skin irritation if

a participant had an allergy to topical isopropyl alcohol or the washable marker, which was applied before skin color readings. Participants were asked if they had any allergies prior to study initiation.

Compensation

The consensual control group was paid for their participation in the prospective arm of the study. Participants received $50 for completing Questionnaire-1, $150 for completing the first forensic examination, and $150 for completing Questionnaire-2 and the second forensic examination. Participants who had a positive pregnancy test received $50 for completing Questionnaire-1 but did not receive payment for the examinations because no exams were completed after a positive pregnancy test.

Sampling

Quota sampling was used to obtain a representative sample of consensual control participants. Using records available from two Sexual Assault Forensic Examiner (SAFE) programs for 3 years, the investigators determined the proportion of sexual assault survivors who belonged in selected age, time interval between assault and exam, and race/ethnic identity strata. Age categories used for quota sampling were 21–24 years, 25–34 years, 35–44 years, 45–54 years, 55–64 years, and 65+ years. Time interval between assault and exam categories was 1–4 hours, 5–8 hours, 9–12 hours, 13–16 hours, 17–20 hours, and 21–24 hours. Race/ethnic identity categories were African American/Black/Black; Hispanic/Latino; Caucasian/White/White Hispanic/Latino; and other (e.g., Asian American, Native American, biracial, multiracial). A 3-way quota sampling matrix was constructed with 108 cells. The proportion of cases within each cell served as the quota that was filled from the proposed sample of 600 consensual control

participants. Ultimately, 528 women were enrolled, and all the required data were completed.

Data Collection

The investigators were permitted to receive de-identified data collected from rape survivors from two sexual assault nurse examiner programs. They included data from 433 rape survivors (nonconsensual group) who were examined by forensic specialists. Data from the nonconsensual group included the presence of ano-genital injury, skin color, and demographic data. Therefore, the total sample was 961 (528 in the consensual group and 433 in the nonconsensual group).

Data from both groups included digital images of injured and non-injured ano-genital areas. The images were captured during the forensic examination. Injury was defined using the acronym TEARS (tears, ecchymosis, abrasions, redness, or swelling; see Table 5; (Slaughter, Brown, Crowley, & Peck, 1997). Examiners for both consensual and nonconsensual groups identified TEARS during visual inspection, colposcopy, and contrast media (toluidine blue) application. They indicated on a Sexual Intercourse Injury Scoring Sheet (SIIIS) the number and location of genital injuries, circled the location on the graphic representation, and took 21 digital images during the exam. A tear was defined as any break in tissue integrity including fissures, cracks, lacerations, cuts, gashes, or rips. Ecchymosis was defined as skin or mucous membrane discolorations, known as bruising or black and blue areas due to the damage of small blood vessels beneath the skin or mucous membrane surface. Abrasions were defined as skin excoriations caused by the removal of the epidermal layer and with a defined edge. Redness was defined as skin that was abnormally inflamed due to irritation or injury,

without a defined edge or border. Swelling was edematous or transient engorgement of tissues. Three locations for ano-genital injury were also documented: the external genitalia (i.e., labia majora, labia minora, periureteral area, perineum, posterior fourchette, and fossa navicularis), internal genitalia area (i.e., hymen, vagina, cervix), and the anus (i.e., rectum).

Secondary Analysis

This dissertation study provided a secondary analysis with data from a combination of the two longitudinal, observational parent studies. By using both studies, the sample size was increased and satisfied the number of subjects required for the path analysis model of fit for confirmatory factor analysis (CFA). Secondary analysis studies with larger samples sizes allow for more representation of the target audience (Trzesniewski, 2011). I contributed to the original studies as a member of the team serving as a research assistant and was involved during the initial participant recruitment for RO1NR005352 and with data collection for both studies. I was also responsible for the initial protocol development for the corneometer, the instrument used to determine skin hydration (see below).

Data Collection

For the secondary analysis, only baseline data collected from the consensual control study population were used. The choice to use baseline rather than follow-up (second forensic examination) was made for two reasons. First, the skin variables (i.e., skin hydration, skin elasticity, and skin color) were obtained during the first exam. Therefore, the skin injury data and other skin variables would be collected

contemporaneously if baseline data were used. Second, the sample size was larger for the first examination because a small number of participants did not return for the second examination. No data from the sexual assault survivors were used in the secondary analysis.

Study Population

The sample was comprised of 353 females from the 528 participants in the consensual group. This number was selected because all 353 had complete data for all skin variables. The sample population were females between the ages 21–65. At the start of the parent study, skin elasticity and skin hydration were not collected, but were added after data collection was initiated.

IRB Approval: Human Subjects Consideration

Institutional review board (IRB) approval for this secondary analysis was obtained under the Parent Study Sommers IRB protocol (805591). The secondary analysis work was drawn directly from the Sommers work and, as principal investigator for the dissertation study, I was added as a co-investigator at the start of my doctoral program. No new data were collected, and the variables remained the same. See Appendix A for the most current renewal.

The dissertation study involved indirect research with human subjects, as it entailed analysis of the secondary dataset of key variables collected in the parent study. IRB approval was obtained in 2009 as a part of the original IRB approval. The protocol was reviewed and reapproved using the expedited procedure set forth in 45 CFR 46.110(b) (9), on 05-May-2017. Following that date, annual IRB renewals of the parent study were no longer required by the University of Pennsylvania IRB.

Transfer Procedure

The data source for the dissertation study was from the two parent studies. The data from the parent studies were housed at Utah State University, under the control of co-investigator Jamison Fargo, PhD. The principal investigator (Sommers), the co-investigator (Fargo), and I discussed the data that were needed to meet the study aims. I met with Dr. Fargo and worked in his lab to access the main database and to extract and create a copy of the identified data set. The data copy was stored on a password-protected computer on a secure server. The copy was needed to address the study's aims and is maintained at Utah State University with full access to the data when required for the principal and co-investigator of the parent study. The study variables and the source of the data are explained in Table 4.

Table 4

Variables and Data Sources for Study

Variable	Definition	Measurement strategy and location of data	Variable construction	Variable type	Variable unit of measurement
Skin hydration	Water content of the stratum corneum (Dobrev, 2000).	Corneometer CM 825 (Courage+Khazaka) Data collection sheet	Dielectric constant of water is 81 and other substances >7 are different arbitrary (AU)	Continuous	Very Dry <30 AU Dry 30-40 AU Normal >40 AU
Skin color	Observed pigmentation resulting from the selective absorption and scattering of light wavelengths (Pierard, 1978)	Color Tec Spectrophometer using the CIE L*a*b* Data Collection Sheet: Q39 & Q43	L= black [0] to white [100] Chroma/ brilliance Color space a* = positive (red) to negative (green)	Continuous	L* 0 to 100 a* 128 to 127 b* 128 to 127
Viscoelasticity	The ability of the skin to change shape under tension and return to its original position wen stretched. Ratio of elastic recovery and elastic	Cutometer MPA 580 (Courage+Khazaka electronic GmbH) Data collection sheet: Results & Graphs	Biological elasticity (Ur/Uf) Ur- immediate relaxation Uf- final relaxation Measurement of viscoelastic formation and application of	Continuous	R7 0-1.0

Variable	Definition	Measurement strategy and location of data	Variable construction	Variable type	Variable unit of measurement
	deformation (Everett & Sommers, 2013; Langton, Graham, et al., 2017).		force and elastic retraction on release		
Age	Number of calendar years since birth at the time of data collection	Self-report age in calendar years Data collection sheet	Number of years from birth to date of examination	Continuous	Age > 20 years
BMI	Weight in kilograms divided by the square of height in meters	Mass scale Stadiometer Data collection sheet (Q11-12, Q28a)	Weight (Kg/ht^2)	Categorical	Underweight <18.5 Normal 18.5-24.9 Overweight 25.0-29.9

Instruments and Measurement Strategies

To understand the secondary data analysis, an explanation of the instruments and the measurement strategies used for data collection in the parent study follows.

Corneometer

Skin hydration measurements were made with a Corneometer® CM 825 (Courage + Khazaka electronic GmbH, Kőln, Germany). The instrument was developed in 1980 and is recognized as the gold standard for hydration assessment of the SC. It is noninvasive and reflects the water content of the superficial epidermal layers down to a depth of 0.1 mm. The principle is based on the capacitance measurement of a medium, the SC, which acts as a dielectric (Heinrich et al., 2003). As a dielectric, the SC transmits an electrical force without conduction. In the parent study, skin hydration was measured using the Corneometer capacitance method. In a capacitor, one metal plate has an excess of electrons (yields a negative charge) and the other plate lacks electrons (yields a positive charge (Heinrich et al., 2003).The identified dielectric, the SC, has the capability to influence changes in the capacitor. Water increases the capability of the capacity by a factor of approximately 81 as compared with most substances.

The Corneometer® 825 measures skin hydration in arbitrary units (AU) from 0 to 130 inclusive. Designations are: less than 30 A.U. is very dry SC; 30-45 A.U. is dry SC; and greater than 45 A.U. is considered sufficiently moisturized SC. The instrument does not directly measure skin hydration but evaluates the water-holding capacity of the SC, which reflects the skin surface hydration and skin barrier efficiency (Tagami & Yoshikuni, 1985; Tanaka, Zhen, & Tagami, 1997).

The corneometer remains the gold standard in skin hydration measurement however current research and innovation in skin hydration measurement is an evolving area of skin science. Handheld and wearable non-invasive instruments that evaluate SC hydration levels and the skin integrity are available. The new technologies include instruments that incorporate bioimpedance, diffuse reflectance spectroscopy (DRS) based systems and wearable monitoring (Hall & Phillips, 2005; Hsu, Cheng, Yang, Yen, & Tseng, 2022; Schiavoni et al., 2020). In addition to skin injury, current research investigating skin hydration is occurring in a variety of settings. Additional areas include the cosmetic industry, medication monitoring to evaluate the effectiveness of estrogen regulation in menopausal women and other areas of medical dermatology are constantly opening other areas for research (Alam, Gladstone, & Tung, 2009; Amabile et al., 2022).

Cutometer

Measurements of viscoelasticity were made non-invasively with a Cutometer® MPA 580 (by Courage + Khazaka electronic GmbH, Kőln, Germany), which, uses the vacuum principle, sucks up a defined area of skin surface and records it optically. Analysis of the visual recorded measurement curves makes it possible to determine the elastic and plastic characteristics of the skin. Measures include elastic recovery (in millimeters, 0.1 second after release of negative pressure), elastic deformation (in millimeters, total displacement from initial position at maximum negative pressure), and biological elasticity (ratio of elastic recovery to elastic deformation). We used the variable R7 for the elasticity measurement. R7 is the ratio between elastic recovery and elastic deformation in millimeters. R7 measures 0.1 second after the negative pressure release and elastic deformation and is the total displacement from the initial position to

maximum negative pressure (Choi et al., 2013; Wissing & Müller, 2003). A higher value indicates skin is more elastic.

Spectrophotometer

The reflectance spectrophotometer (Color Tec-PSM©) is a hand-held instrument that is designed to measure skin color. Color is the result of selective absorption and scattering of light wavelengths from the dermis (Yun, Lee, Rah, Kim, & Park, 2010). The instrument obtains reflectance values from colored surfaces and returns the entire reflectance spectrum as well as L*, a*, and b* values. The instrument is calibrated at the factory by CIELAB standards; quality control procedures prior to each data collection session allow for testing of the full range of colors against known L*, a*, and b* values. It operates by shining a light of a specific wavelength using a filter and is used to measure the intensity of light reflected by the skin. This type of spectrophotometer continues to be recognized as the gold standard for skin color measurements and has been tested extensively in the cosmetics industry as well as by scientists investigating ultraviolet ray exposure to the skin.

Stadiometer, Weight Scale and BMI

The participant's height and weight were measured using the stadiometer and weight scale. The instrument was an eye-level mechanical beam scale with a height rod that is registered through the International Organization for Standardization (ISO). After the scale was calibrated to zero, participants were asked to remove outer garments (coats or jackets), shoes and step on the scale to be weighed. The height was measured by the participants facing forward and the rod touching only the top of their head. The height and weight measurements were recorded and used to calculate the body mass index

(BMI). A measure of body fat that is based on height and weight is the BMI. The English units were converted to metric units and the BMI is expressed in units of kg/m^{2}.

Sexual Intercourse Injury Scoring Sheet

The Sexual Intercourse Injury Scoring Sheet (SIISS) is a rating instrument (see Appendix B) for the assessment of genital injuries that incurred during sexual intercourse. The instrument used by the parent study, was based on previous work by Slaughter but modified and refined by the Sommers research team (Slaughter, Brown, Crowlwy, & Peck, 1997). The instrument was used to count the frequency and prevalence of injuries and also draw the injury locations on a body diagram based on the TEARS model as previously described. The instrument itself and data from the instrument were assessed for content validity by a panel of experts including a primary care physician, two sexual assault nurse examiners, a researcher in the area of marital rape, a researcher in the area of intimate partner violence, and two gynecologists with experience in colposcopy. Based on the feedback of the experts, and the extensive research done by Sommers as a subject matter expert, the instrument was revised and refined prior to data collection (Sommers, 2007).

Skin Color

Skin color is the result perceived pigmentation from the selective absorption and scattering of light wavelengths from the dermis of the human body (Pierard 1998). The skin color is constitutive unexposed (untanned) area of the skin which is the true genetic determined color. Skin color is measured by quantification of selected light wavelengths corresponding to the color of biologic chromophores such as melanin, carotene, and hemoglobin. Skin color was quantified with the variables L*, a*, and b*, which were

obtained from the tristimulus values (the amounts of three primary colors that specify a color stimulus).

Sun Exposure

Damage from the sun can be immediate or long-term. Immediate damage manifests as erythema and sunburn, which causes cell tissue degradation and disrupts the skin's integrity (Mizuno et al., 2016; Wan et al., 2017) UV light decreases collagen and elastin and alters the cross-linked structure of the collagen and elastin fibers within the extracellular matrix (Knuutinen et al., 2002; Pillet et al., 2017). Sun exposure in this study was measured by using a questionnaire asking the following question: In the past 12 months, how many times did you have a red, blistering, or painful sunburn that lasted a day or more? The measurement was the participants perceived understanding of experiencing sunburn. In the path analysis, the variable was coded as nominal variable and entered as Y-yes sunburn or N- no sunburn.

Smoking

Smoking status was measured by asking the following question: In the past 6 months, on average, how many cigarettes/tobacco do you smoke/use a day? For the path analysis the variable was coded as a nominal variable and entered as Y-yes smoker or N-non-smoker.

Skin Injury

Injury is the physical damage that results when the human body is suddenly or briefly subjected to intolerable levels of injury (Holder et al., 2001). Epidermal injury is localized damage to the outer layer of the skin. In this study, skin injury was measured during visual inspection, colposcopy and contrast media application by the presence and

frequency of visual tears and abrasions. A tear was defined as any break in tissue integrity including fissures, cracks, lacerations, cuts, gashes, or rips. Abrasions were defined as skin excoriations caused by the removal of the epidermal layer and with a defined edge. In the path analysis the variable were coded as present Yes or No. If an injury was present the number of tears and abrasions were counted using data that was entered from the skin injury tool (SIISI).

Statistical Analysis

Descriptive statistics were used to describe the sample computed for all study variables. The Pearson product-moment correlation coefficients were computed for all bivariate relationships among the continuous variables using SPSS (IBM SPSS Statistics for Windows, Version 23.0.) These statistics as well as other exploratory methods, including scatterplots, examined the data for possible values, outliers, and other abnormalities (such as linearity), prior to conducting the statistical modeling.

We used path analysis for the estimates of the path to empirically evaluate the theoretical model. Each specific aim was tested using the M plus software with the WLSMV estimator (a robust weighted least square estimator), due to the presence of a categorical outcome variable (i.e., skin injury prevalence) (Muthén, 2010). Path analysis is an extension of multiple regression and provides estimates of the magnitude and significance of hypothesized relationships between sets of variables (Everitt & Dunn 1991). In path analysis, all variables are observed. Unlike models that include latent variables, path models assume perfect measurement of the observed variables; only the structural relationships between the observed variables are modeled. The path analysis model is often used when one or more variables are thought to mediate the relationship

between two others (Muthén, 2010). For this secondary analysis, the model was tested if hydration mediated the relationship between the exogenous variables and the endogenous various skin injury prevalence and frequency.

Path analysis has many advantages over conducting a series of separate regression analyses. A path model allows multiple outcomes or dependent variables, the specification and assessment of mediating paths or relationships in the model and allows for tests of the overall fit of a hypothesized structure to the data, which corresponds to theory (Gunzler et al., 2013; Levant et al., 2013). Four outcome variables are included in the path model: skin injury frequency, skin injury prevalence, hydration, and elasticity. Hydration, elasticity, and constitutive skin color also served as mediating variables in the path model, or as intermediates between demographic, physiologic and behavioral variables, and skin injury prevalence and frequency on the other. The theoretical model illustrated in Figures 3 and 4 examine the relationship among two or more variables. Correlation does not establish causality, but the path analysis can provide evidence regarding the nature and direction of the casual influence among the variables (Polit et al., 2012). Each specific aim was addressed by a statistical test (or tests) of the pathway(s) between predictor and outcome variables. With a sample of 351 women and up to 11 observed variables in the path model, we had a ratio of approximately 31 participants per variable, which well exceeded the standard rules of thumb of 10–20 participants per variable (Nunnally, 1967)

The aims for the secondary analysis were derived directly from Aim 3 of the parent study. In the parent study, aim 3 investigated the relationship between variation in skin mechanics (i.e., skin elasticity and skin hydration) and other factors (i.e., skin color,

age, BMI, total body water, body composition (fat mass and fat-free mass), estrogen level, sun exposure, and health status (smoking) on ano-genital injury prevalence and frequency in Black, White, and Latina women, and women of other ethnicities following consensual sexual intercourse.

Each specific aim of the secondary analysis was tested using the M plus software with the WLSMV estimator (a robust weighted least square estimator), due to the presence of a categorical outcome variable (i.e., skin injury prevalence). The following was used to determine adequate model fit: a Comparative Fit Index (CFI) ≥ .95 (Hu & Bentler, 1999), a maximum Root Mean Square Error of Approximation (RMSEA) of .08 (MacCallum, 1996), and a Weighted Root Mean Square Residual (WRMR) ≤ .90 (Yu & Muthén, 2002). A chi-square ($\chi 2$) statistic was not evaluated as an indicator of model fit for the path model as it was conducted using the WLSMV estimator.

CHAPTER 4

The main purpose of this study was to understand how skin hydration influences skin injury prevalence and frequency. The study also examined the influences of other variables such as age, BMI, smoking, and sun exposure, and their relationship to skin hydration and the biomechanical properties skin color and skin viscoelasticity. A secondary analysis was performed to examine the following aims and research hypotheses. Descriptive statistics for the study population are detailed followed by the path analysis results with findings for each identified aim.

Study Aims

Aim 1. To determine physiologic, behavioral, and demographic correlates of skin hydration.

Aim 1a. To determine the direct relationship between the physiologic (BMI), behavioral (smoking status, sun exposure) and demographic (age), correlates of skin hydration.

- Hypothesis 1a. There is a direct relationship between BMI, smoking status, sun exposure, age and the correlate hydration.

Aim 1b. To determine the direct relationship of the biomechanical measures (skin viscoelasticity and skin color) with skin hydration.

- Hypothesis 1b. There is a direct relationship between skin viscoelasticity and skin color and the correlate hydration.

Aim 2. To determine whether skin hydration mediates the relationship between physiologic, behavioral, and demographic variables, and skin injury prevalence and frequency.

Aim 2a. To determine whether skin hydration mediates the relationship between BMI, smoking, sun exposure and age with skin injury presence and frequency.

- Hypothesis 2a. Skin hydration will mediate the relationship between BMI, smoking status, sun exposure and age with skin injury prevalence and frequency.

Aim 2b. To determine whether skin hydration mediates the relationship between skin viscoelasticity and skin color with skin injury prevalence and frequency.

- Hypothesis 2b. Skin hydration will mediate the relationship between skin viscoelasticity and skin color with skin injury prevalence and frequency.

Aim 3. To determine physiologic, behavioral, and demographic correlates of skin injury prevalence and frequency.

Aim 3a. To determine the direct relationship between the physiologic (BMI), behavioral (smoking status, sun exposure) and demographic (age,) correlates of skin injury prevalence and frequency.

- Hypothesis 3a. There will be a direct relationship between BMI, smoking status, sun exposure and age to skin injury prevalence and frequency.

Aim 3b. To determine the direct relationship of biomechanical measures (skin viscoelasticity and skin color) with skin injury prevalence and frequency.

- Hypothesis 3b. There will be a direct relationship between skin viscoelasticity, skin color and skin injury prevalence and frequency.

Aim 3c. To determine if skin viscoelasticity mediates the relationship between BMI, sun exposure, smoking status, and age with skin injury prevalence and frequency.

- Hypothesis 3c. Skin viscoelasticity will mediate the relationship between BMI, sun exposure, smoking status, and age with skin injury prevalence and frequency.

Aim 4. To determine physiologic (BMI), behavioral, and demographic (age) correlates of skin viscoelasticity.

Aim 4a. Determine the direct relationship between physiologic (BMI), behavioral (smoking, sun exposure) and demographic (age) correlates of viscoelasticity.

- Hypothesis 4a. There is a direct relationship between BMI, smoking, sun exposure and age

Aim 4b. Determine if skin viscoelasticity mediates the relationship between BMI, smoking, sun exposure and age variables with skin hydration.

- Hypothesis 4b. Skin viscoelasticity will mediate the relationship between age, BMI, smoking and sun exposure variables with skin hydration

Description of the Sample

A descriptive data analysis was conducted using SPSS (version 20, International Business Machines, Corp. Armank, NY). The analysis was done to describe sample characteristics. Descriptive statistics were computed based on primary grouping variables (i.e., demographic, marital status, race, educational level, behavioral and physiologic).

The final study population consisted of 351 females who were participants in the consensual control groups of the two combined parent studies. Participant ages ranged from 21 years to 68 years old with a mean age of 32.6 years, *SD* = 9.71. Most participants self-identified as Hispanic (55%) followed by White (25%), Black (16 %) and other (2.8%). For the purposes of this secondary analysis, acute or chronic health status was not addressed. The characteristics of the study sample are presented in Table 5.

Table 5

Descriptive Statistics of All Study Variables

Variable	M (or N)	SD (or %)	Median	Minimum
Demographic				
Age	32.60	9.71	30.11	21.00
Marital Status				
Married	82	(23.20)		
Single	227	(64.30)		
Other	44	(12.50		
Race				
Black	58	(16.40)		
White	90	(25.20)		
Hispanic	195	(55.20)		
Other	10	(2.80)		
Education				
<High School	39	(11.00)		
High School	62	(17.60)		
>High School	216	(61.20)		
Missing	36	(10.20)		

Behavioral				
Current smoker (yes)	81	(22.90)		
Sun exposure last 12 months (yes)	78	22.10		
Physiologic				
BMI	28.50	7.85	26.15	15.78
Hydration	25.40	8.02	24.46	7.11
Viscoelasticity	0.69	0.08	0.71	0.34
Skin Color				
L*	54.81	9.82	57.70	29.37
a*	8.54	1.62	8.72	3.59
b*	18.44	2.82	18.55	10.34
Skin Injury				
Frequency of tears and abrasions	0.28	0.91	5.5	0.0
Prevalence of tears and abrasions	294	83.3		

Note. Two participants were missing data on sun exposure

Bivariate correlations among all continuous study variables are presented in Table 6 and measured the strength and directions of the measured continuous study variables. Of note, there was a weak positive correlation between skin hydration and BMI ($r = .301$, $p < .001$). Age and viscoelasticity had a moderate negative correlation ($r = -.457$, $p < .001$). Also, a weak positive correlation existed between skin color L* (brightness) and viscoelasticity ($r = .123$, $p = .021$). There was a moderate positive correlation ($r = .674$, $p < .001$) between skin color a* (red/green) and skin color L* (brightness). Skin color b* (yellow/blue) and skin color a* (red/green) also show a positive correlation ($r = .451$, $p < .001$).

Table 6

Pearson's Correlations Among Continuous Variables

Variable	1	2	3	4	5	6	7	8
Age	-							
BMI	.145**	-						
Hydration	-.120*	.301***	-					
Viscoelasticity	-.456***	-.140**	-.021	-				
Skin Color L	.018	-.097	-.014	.123*	-			
Skin Color a	.025	-.095	.029	-.044	-.674***	-		
Skin Color b	.042	.270***	.128*	.052	-.163**	.451***	-	
Injury Frequency	-.044	.012	-.010	.015	-.041	.017	.067	-

Note. *p < .05, **p < .01, ***p < .001

Results of Path Analysis

Exploratory analyses did not indicate curvilinear relationships between predictor and outcome variables or problems with outliers or impossible values. Two participants were missing data on sun exposure and were excluded from the path analysis, resulting in a sample of 351 women. The initial path model possessed good overall fit with a Comparative Fit Index (CFI) = 0.97, Root Mean Square Error of Approximation (RMSEA) = 0.08 (90% confidence interval = 0.03-0.14), and Weighted Root Mean Square Residual (WRMR) = 0.52. Figure 5 presents the standardized results for the path

model and Figure 6 presents a depiction of the same model, but only with the statistically significant paths included.

Figure 5

Standardized Results for Path Model

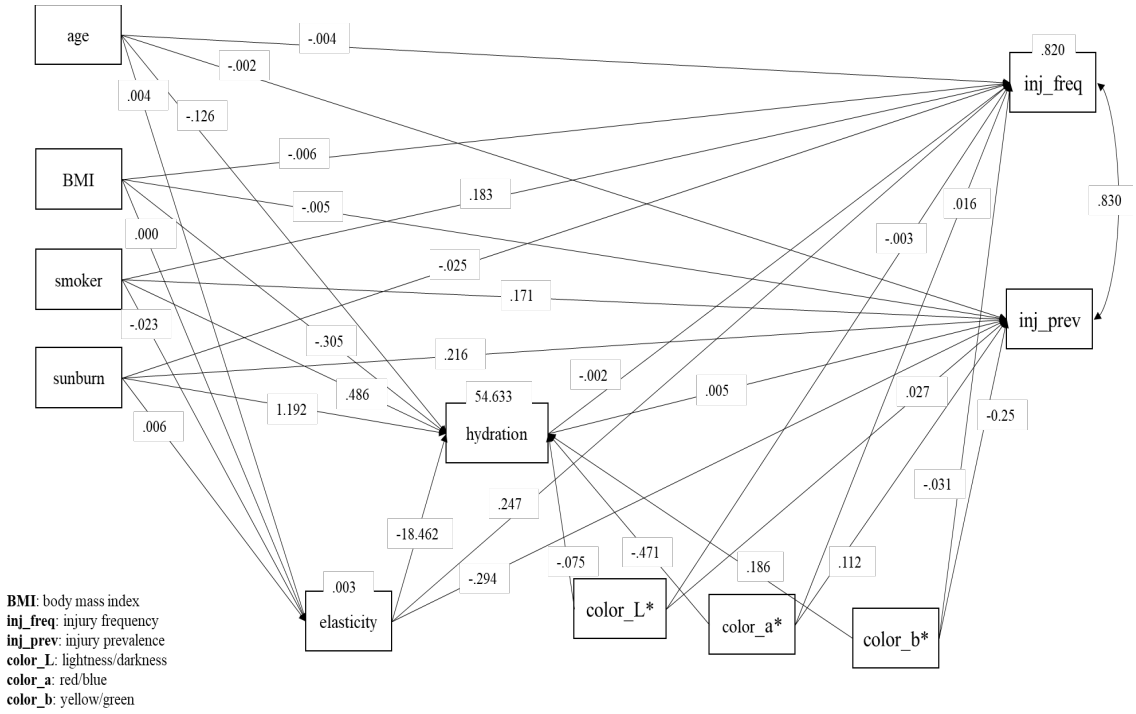
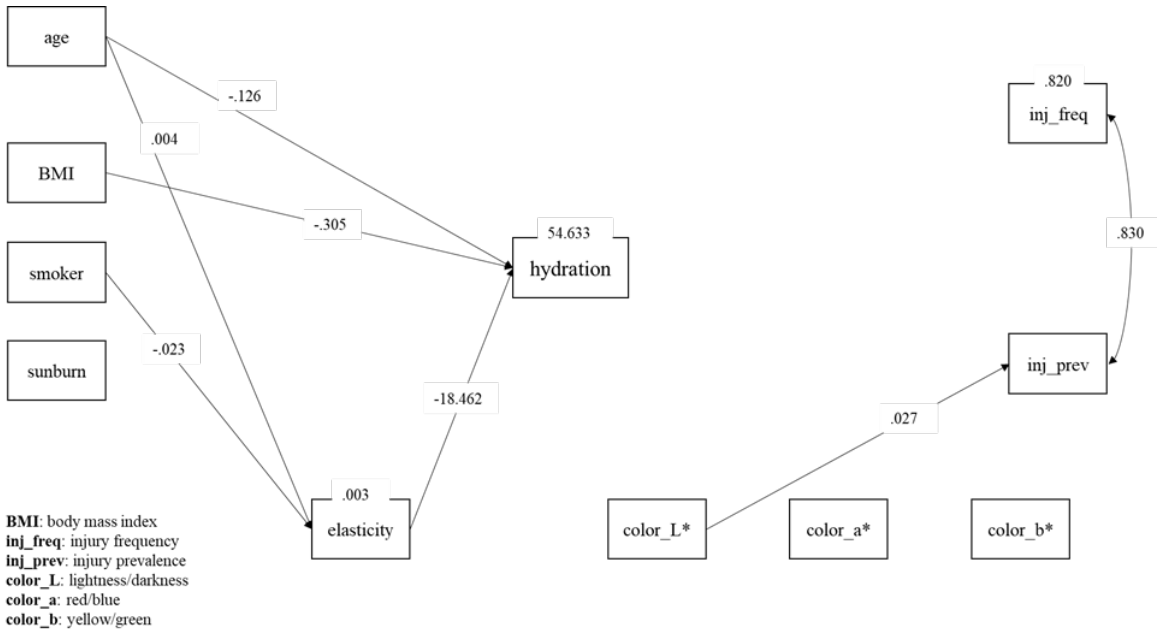


Figure 6

Standardized Results for Path Model with Statistically Significant Paths



Note. The standardized loadings for each path, as well as their associated confidence intervals and p-values, are presented in Table 7.

Table 7

Results of Path Analysis (N=351)

Outcome	Predictor	β	95% CI Lower	95% CI Upper	t-test	p-value
Hydration	Age	-0.15	-0.27	-0.03	-2.55	0.011
	BMI	-0.30	-0.41	-0.19	-5.51	<.001
	Smoker	0.02	-0.07	0.12	0.51	0.609
	Sun Exposure	0.06	-0.04	0.17	1.11	0.266
	Skin Color L	-0.09	-0.22	0.03	-1.41	0.157
	Skin Color a	-0.09	-0.24	0.04	-1.32	0.186
	Skin Color b	0.06	-0.04	0.17	1.17	0.239
	Viscoelasticity	-0.16	-0.30	-0.02	-2.31	0.021
Viscoelasticity	Age	-0.54	-0.62	-0.45	-12.33	<.001
	BMI	-0.03	-0.15	0.09	-0.500	0.614
	Smoker	-0.13	-0.24	-0.03	-2.530	0.011
	Sun Exposure	0.03	-0.08	0.16	0.550	0.578
Injury frequency	Hydration	-0.01	-0.14	0.12	-0.20	0.839
	Viscoelasticity	0.01	-0.13	0.17	0.24	0.809
	Age	-0.03	-0.21	0.13	-0.43	0.665
	BMI	-0.05	-0.23	0.13	-0.54	0.587
	Smoker	0.08	-0.07	0.24	1.02	0.307
	Sun Exposure	-0.01	-0.20	0.18	-0.11	0.906
	Skin Color L	-0.03	-0.26	0.19	-0.31	0.752
	Skin Color a	0.02	-0.22	0.28	0.22	0.824
	Skin Color b	-0.09	-0.27	0.08	-1.03	0.301
Injury prevalence	Hydration	0.03	-0.14	0.21	0.40	0.685
	Viscoelasticity	-0.02	-0.24	0.20	-0.17	0.862
	Age	-0.01	-0.20	0.17	-0.18	0.855
	BMI	-0.03	-0.20	0.12	-0.47	0.633
	Smoker	0.07	-0.09	0.23	0.82	0.409
	Sun Exposure	0.08	-0.06	0.23	1.14	0.253
	Skin Color L	0.25	0.02	0.48	2.21	0.027
	Skin Color a	0.17	-0.08	0.43	1.36	0.171
	Skin Color b	-0.06	-0.27	0.14	-0.64	0.517

Note. Standardized results of tests of mediated effects, as well as their associated confidence intervals and p-values, are presented in Table 8.

Table 8

Tests of Indirect (Mediating) Effects from Path Analysis (N=351)

Outcome	Mediator	Predictor	β	95% CI Lower	95% CI Upper	t-test	p-value
Hydration	Viscoelasticity	Age	0.087	0.125	0.161	2.251	0.024
		BMI	0.005	-0.014	0.024	0.492	0.623
		Smoker	0.022	-0.003	0.047	1.694	0.090
		Sun Exposure	-0.006	0.027	0.015	-0.54	0.589
Injury prevalence	Hydration	Age	-0.006	-0.034	0.020	-0.40	0.693
		BMI	-0.011	-0.065	0.040	-0.40	0.697
		Smoker	0.001	-0.005	0.010	0.32	0.749
		Sun Exposure	0.002	-0.010	0.010	0.38	0.704
		Viscoelasticity	-0.006	-0.036	0.020	-0.39	0.695
		Skin Color L	-0.003	-0.020	0.010	-0.39	0.697
		Skin Color a	-0.004	-0.021	0.010	-0.39	0.698
		Skin Color b	0.002	-0.010	0.020	0.38	0.703
	Viscoelasticity	Age	0.011	-0.111	0.132	0.17	0.862
		BMI	0.001	-0.007	0.010	0.16	0.869
		Smoker	0.003	-0.028	0.030	0.17	0.862
		Sun Exposure	-0.001	-0.009	0.010	-0.17	0.868
	Viscoelasticity →Hydration	Age	0.003	-0.013	0.019	0.39	0.695
		BMI	0.000	-0.001	0.001	0.31	0.758
		Smoker	0.001	-0.003	0.005	0.39	0.695
		Sun Exposure	0.000	-0.002	0.001	-0.32	0.750
Injury frequency	Hydration	Age	0.002	-0.018	0.022	0.20	0.838
		BMI	0.004	-0.035	0.043	0.20	0.839
		Smoker	0.000	-0.004	0.003	-0.19	0.853
		Sun Exposure	-0.001	-0.009	0.007	-0.20	0.842
		Viscoelasticity	0.002	-0.019	0.023	0.21	0.838
		Skin Color L	0.000	-0.011	0.013	0.20	0.841

Outcome	Mediator	Predictor	β	95% CI Lower	95% CI Upper	t-test	p-value
		Skin Color a	0.001	-0.011	0.014	0.20	0.841
		Skin Color b	-0.001	-0.010	0.008	-0.20	0.840
	Viscoelasticity	Age	-0.010	-0.093	0.072	-0.24	0.809
		BMI	-0.001	-0.006	0.005	-0.21	0.849
		Smoker	-0.003	-0.024	0.019	0.24	0.810
		Sun Exposure	0.001	-0.005	0.007	0.22	0.825
	Viscoelasticity →Hydration	Age	-0.001	-0.012	0.010	-0.21	0.838
		BMI	0.000	-0.001	0.001	-0.19	0.849
		Smoker	0.000	-0.003	0.003	-0.20	0.839
		Sun Exposure	0.000	-0.001	0.001	0.19	0.847

Note. The proportion of variance explained in each outcome variable as a function of all associated predictor variables is presented in Table 9.

Table 9

Proportion of Variance Accounted for in Outcomes of Path Model (N=351)

Outcome	R^2	p-value
Viscoelasticity	0.13	<.001
Hydration	0.33	<.001
Injury frequency	0.02	0.192
Injury prevalence	0.06	0.119

Although results showed that a significant proportion of the variance in viscoelasticity (13%, $p < 0.001$) and hydration (33%, $p < 0.001$) were accounted for in the path model, variation in injury prevalence (6%) and frequency (2%) were not significantly accounted for (each $p > .05$). Each specific aim was addressed by a

statistical test (or tests) of the pathway(s) between predictor and outcome variables. The result for each specific aim follows.

Results

Demographic, Behavioral, and Physiologic Correlates of Skin Hydration

Aim 1a. To determine the direct relationship between demographic (age), physiologic (BMI), and behavioral (smoking, sun exposure) correlates of skin hydration. Results showed that demographic and physiologic correlates were significantly associated with skin hydration, but behavioral correlates were not. For example, a 1 SD-unit increase in age was associated with a 0.15 SD-unit decrease in skin hydration level ($p = 0.011$). In other words, a 10-year increase in age was associated with, on average, a 1.2-unit decrease in skin hydration. Additionally, 1 SD-unit increase in BMI was associated with a 0.30 SD-unit decrease in skin hydration level ($p = <0.001$). Said differently, for every 8-unit increase in BMI, skin hydration decreased by 2.41 units on average.

Aim 1b. Determine the direct relationship of physiologic measures (skin viscoelasticity and skin color) with skin hydration. Skin color values were not significantly associated with skin hydration level. However, viscoelasticity was negatively significantly associated with skin hydration level, in that a 1 SD-unit increase in viscoelasticity was associated with a 0.16 SD-unit decrease in skin hydration level ($P = .021$). In other words, a 0.08 increase in viscoelasticity was associated, on average, with a 1.28 decrease in skin hydration.

Skin Hydration as a Mediator of the Relationship between Demographic, Behavioral, and Physiologic Variables, and Skin Injury Prevalence and Frequency

Aim 2a. Determine whether skin hydration mediates the relationship between age, BMI, smoking, and sun exposure with skin injury prevalence and frequency. Skin hydration was not a significant mediator for any relationship between demographic and behavioral predictors and skin injury prevalence and frequency outcomes.

Aim 2b. Determine whether skin hydration mediates the relationship between skin viscoelasticity and skin color with skin injury prevalence and frequency. Skin hydration was not a significant mediator for any relationship between skin color and viscoelasticity physiologic predictors and skin injury prevalence and frequency outcomes.

Demographic, Behavioral, and Physiologic Correlates of Skin Injury Prevalence and Frequency

Aim 3a. Determine the direct relationship between demographic (age, BMI) and behavioral (smoking, sun exposure) correlates of skin injury prevalence and frequency. Demographic and behavioral variables were not significantly associated with skin injury prevalence and frequency.

Aim 3b. Determine the direct relationship of biomechanical factors (skin viscoelasticity, skin hydration, and skin color) with skin injury prevalence and frequency. Results showed that only skin color L-values significantly predicted skin injury prevalence (p = .027), with a 29% increase in odds of injury for everyone SD-unit increase in L-values (adjusted odds ratio = 1.29, 95% CI = 1.03-1.62). In other words, for every 10-point increase in L-values, the odds of injury prevalence increase by almost 30%, on average. No variables were found to significantly predict skin injury frequency.

Aim 3c. Determine if skin viscoelasticity mediates the relationship between demographic (age, BMI) and behavioral (sun exposure, smoking) factors and skin injury prevalence and frequency. Viscoelasticity was not a significant mediator for any relationship between the set of demographic and behavioral predictors and the outcomes of skin injury prevalence and frequency.

Demographic (Age), Physiologic (BMI) and Behavioral (Smoking, Sun Exposure) Correlates of Viscoelasticity

Aim 4a. Determine the direct relationship between demographic (age), physiologic (BMI), and behavioral (smoking, sun exposure) correlates of viscoelasticity. Results showed that age was negatively associated with viscoelasticity, with a 0.54 SD-unit decrease in viscoelasticity for every 1-SD unit increase in age ($p < 0.001$). In other words, for every 10-year increase in age, viscoelasticity decreased by an average of 0.04 units. Additionally, on average, viscoelasticity for current smokers was 0.13 SD-units lower than non-smokers ($p = 0.011$). This translates into a 0.01-unit difference, on average, in viscoelasticity between smokers ($M = 0.67$, $SD = 0.09$) and non-smokers ($M = 0.70$, $SD = 0.08$).

Aim 4b. Determine if skin viscoelasticity mediates the relationship between age, BMI, smoking and sun exposure variables with skin hydration. Results showed that viscoelasticity served as a significant mediator in the relationship between age and skin hydration ($p = 0.024$). The standardized indirect or mediating effect of age on skin hydration through viscoelasticity was 0.09 (95% CI =.09) This indicated that age not only had a direct effect on skin hydration, but that the effect of age was transmitted to skin hydration through viscoelasticity. The mediating effect of viscoelasticity between

smoking and skin hydration approached, but did not reach, statistical significance (estimate = 0.02, $p = 0.090$). Viscoelasticity was not a significant mediator in the relationship between skin hydration and either BMI or sun exposure.

Summary

In summary, the final sample consisted of 351 women ranging from 21 to 65 years of age. Our results showed that in this study population both increased age and BMI were associated with decreased skin hydration and there is a negative association with viscoelasticity and hydration. Skin hydration was not a mediator for any of the identified variables and it did not mediate any relationship between skin color or viscoelasticity with skin injury prevalence or frequency. There was not a direct relationship associated with the identified variables and skin injury prevalence and frequency. However, skin color value L was found to be a significant predictor of skin injury prevalence.

There was a direct relationship between the biomechanical property viscoelasticity and age. As age increased, the elasticity measurement decreased. There was also a relationship with identified smokers and viscoelasticity. Finally, viscoelasticity was a significant mediator in the relationship between age and skin hydration. Also, of note, the mediation effect of viscoelasticity, smoking and skin hydration approached but did not reach significance.

CHAPTER 5

The present study examined the relationships among skin hydration and the variables age, BMI, smoking, and sun exposure with skin injury prevalence and frequency. The study also sought to understand if skin hydration accounted for the variability of skin injury prevalence and frequency in the identified population. Finally, the study investigated the relationship of skin hydration and the biomechanical properties skin color and skin elasticity and their impact on skin injury prevalence and frequency.

This secondary analysis used cross-sectional data collected from the two parent studies: "Injury from Sexual Assault: Addressing Health Disparities" (Sommers, PI-RO1NR005352) and "Injury in Latina Women after Sexual Assault: Moving Toward Health Care Equity" (R01NR011589). The final sample population consisted of a combination of 351 females between the ages of 21 and 65 from the two parent studies.

Skin Hydration related to BMI, Age, Smoking and Sun Exposure

BMI and Skin Hydration

This study revealed a negative association between BMI and skin hydration. As the measurement values for BMI increased, the arbitrary units for skin hydration decreased. BMI does not measure body fat directly, but the value is moderately correlated with more direct measures of body fat (Centers for Disease Control, 2021). The standard BMI weight status for adults is: underweight < 18.5, normal weight 18.5–24.99, overweight > 25.00, and obese > 30.0. The hypotheses that a relationship exists between BMI and skin hydration was supported. The study result was consistent with several prior studies in the literature that investigated the relationship between obesity and skin hydration. In one study, the correlation between BMI and epidermal sensitivity was

examined before and after an irritant patch test with sodium lauryl sulphate (SLS). The results found increased transepidermal water loss (decreased skin hydration) in the experimental obese group (BMI greater than 30) (Wang et al., 2022), as compared to the control normal weight group (Loffler et al., 2002). This result was also found in the pediatric population. In a study to determine the impact of obesity and barrier function in children, investigators found higher TEWL values in obese children compared to normal-weight children (Nino et al., 2012).

Additional studies have demonstrated that obesity is often associated with dry skin, lower hydration, and itching that leads to diminished skin barrier function and injury susceptibility (Brown et al., 2004; Nino et al., 2012). The skin disturbances may be due to obesity-related physiological, progressive changes such as diabetes (insulin resistance), high blood pressure, or problems with the temperature regulating system within the skin (Iacopi et al., 2020; Yosipovitch et al., 1998). In patients with diabetes, hyperglycemia affects the skin by inhibiting keratinocyte proliferation and slows keratinocyte migration to the SC which in turn can lead to a less effective skin barrier (Wang et al., 2022). Skin disorders in patients who have been diagnosed with diabetes are highly correlated with increased blood glucose levels. As an example, Foos et al. 2006 conducted a study with 403 patients diagnosed with diabetes mellitus and evaluated their skin disorders and glycemic control. The study demonstrated that 94% of patients with inadequate glycemic control had some skin disorder; on the other hand, only 60% of patients with diabetes and adequate glycemic control reported any skin disorder. Given this information, in our study, it may have been more revealing if the study questionnaire

included specific questions related to diabetes, such as disease presence and average glucose levels in addition to recording BMI levels.

However, the literature also revealed that increased BMI values and decreased hydration was not universal with all study findings. In a few studies, the body's largest organ appeared to experience the obesity paradox that is similarly seen in some other organs (Shipman & Millington, 2011). The obesity paradox and skin are a hypothesized phenomenon that means increased body weight may, counterintuitively, be a positive influence on an organ or a chronic condition such as cardiovascular disease or chronic renal failure (Shipman & Millington, 2011). One particular study suggested that increased BMI is also associated with greater survival in certain groups of people, such as very elderly individuals or those with certain chronic diseases (Compher et al., 2007) An additional study looked at women who BMI levels ranged from normal weight to morbidly obese (Bae et al., 2010) Results found that epidermal hydration improved up to a certain weight. It can be graphically represented in an inverted U-shaped fashion. Once the weight met a peak and continued to increase, the protective benefits decreased. In skin physiology, the obesity paradox may be partially explained by the interaction of the two lower layers of the skin, the dermis and hypodermis or adipose tissue. Additional studies that include measuring both the elasticity and bioimpedance measurements comparing different weight groups may reveal further information on the obesity paradox for skin physiology.

Age and Skin Hydration

The skin aging process is related to numerous functions and morphologic changes within the stratum corneum (Pappas et al., 2013). The changes are influenced by both

intrinsic and extrinsic factors (Fiedler et al., 2012; Trojahn et al., 2015; Tzaphlidou, 2004). The summative effect of the aging process on skin hydration results in a less effective barrier with greater increased risk or threats to the skin integrity (Huh et al., 2002). Based on the age-related changes, we hypothesized a relationship would exist between age and skin hydration. Specifically, as age increased, the skin hydration levels of the participants would decrease. The age-related findings were consistent with other studies. Previous studies on examining skin integrity evaluation have revealed similar results regardless of sex, body location or numerous extrinsic factors (Hahnel et al., 2017; Kottner et al., 2019; White-Chu & Reddy, 2011). The similar and consistent findings reveal an increased need to focus on risk reduction and the development of evidence-based skin care strategies for maintaining skin integrity in the aged (Lichterfeld-Kottner, Genedy et al., 2020).

A systemic review published in 2013 by Kottner et al. found empirical evidence that supported preventive skin care in the older population was rare. A more recent systematic review (Kottner et al, 2020) was conducted to summarize the empirical evidence of skin care interventions for the older population based on clinical and interventional studies. Sixty-nine articles were included in the overall results of the systematic review. Overall, basic skin care strategies including low-irritating cleansers and moisture retaining products with low pH improved and helped maintain the skin barrier. The results of this review are important and related to our study aims of exploring relationships related to skin injury prevalence and frequency. The average age of the study population was 35, the relatively younger age may have affected the strength of the

finding. If the population had been older, based on the literature and results from previous studies, we may have seen a greater influence of increased age and decreased hydration.

Cigarette Use and Skin Hydration

There was no statistically significant relationship noted between the cigarette use and hydration in the model. This was a surprising finding given the highly toxic substances found in cigarettes and the known consequences of nicotine exposure in disrupting the epidermal barrier function and its effect on skin hydration in most populations (Ortiz & Grando, 2012; Prieux et al., 2020; Rajagopalan et al., 2016; Wolf et al., 1992). During the initial interview at the first visit, participants were asked about cigarette use. Several possible explanations exist for the finding. Nicotine use and the free radical damage does have a cumulative effect on the skin but varies according to body locations (Rajagopalan et al., 2016; Wolf et al., 1992). If the hydration measurements had been collected at the areas of the face such as the cheeks or upper lips versus the inner thigh of the participants who self-identified as smokers, there may have been a significant effect. Also, one of the major contributors to extrinsic skin aging is cigarette use, to that end, if most of the study population was older the results may have been significant (Farage et al., 2008a; Trojahn et al., 2015).

Another possible research question to consider for future studies would be the use of e-cigarettes (vaping) and their effect on the epidermal barrier function. The alternate cigarette use has increased over the past decade. The cartridges from the e-cigarettes are filled with both nicotine and other harmful substances such as propylene glycol, glycol, and chemicals to enhance the flavoring (Dada, 2019; Hahn et al., 2014; Kim & Baum, 2015). Vaping is more common among teens and young adults and has been marketed as

a safer alternative to cigarette use. More research is needed but several studies have found that vaping can cause decreased cutaneous hydration and may contribute to skin's barrier disruption (Schäfer & Werner, 2015; Shujun Xin et al., 2016).

Skin Viscoelasticity and Skin Hydration

The skin's viscoelasticity is affected by epidermal hydration as demonstrated previously (Dobrev et al. (2000). According to the literature, skin viscoelasticity is the product of a synergistic relationship between solid structures and the fluid components of the skin which allows the skin to efficiently respond to deforming challenges when force is applied. In theory, fluid or hydration should increase the level of viscoelasticity. According to the path analysis, the skin viscoelasticity and epidermal hydration were negatively correlated, viscoelasticity increased, and skin hydration decreased. This was a surprising finding, and it may be related to BMI. The average BMI value for this study population was 28.5 (obese). Given the finding that BMI and hydration were negatively associated, there may be some unknown relationship between BMI, hydration and viscoelasticity that was not explored.

Skin Color and Skin Hydration

In 2008, Sommers et al. found that differences in skin measurements were not due to race or ethnicity but related to skin color and the biomechanical mechanisms. Color is the perceived pigmentation resulting from selective absorption, reflection, and light scattering from the dermis layer of the body (Pierard, 1978). In the physiological model of the study, skin color was presented as a biomechanical variable and the aim was to explore the relationship between skin color and hydration. The results of this study found skin color values were not significantly associated with skin hydration levels. No

previous studies were found that contradicted this result. It may appear that darker pigmentation looks more moisturized or hydrated due to the decrease of light scattering, reflection, and absorption primarily at the SC level but there were no differences in actual hydration values (Jiang & Delacruz, 2011). Skin color does vary at different body locations, and we might have yielded different results if the hydration and color values were taken at several areas of the body instead of only at the inner thigh which may be a limitation in this study.

Viscoelasticity Level in Smokers

In this study, it was also noted that smokers had a lower elasticity value than non-smokers. Toxins from the nicotine damage the dermis; as a result, the skin is less able to change shape and return to the original position which increases the risk for potential injury. This finding is consistent with previous studies on the same topic. A recent study (Yazdanparast et al., 2019) found gross elasticity was significantly lower in smokers than non-smokers ($p = 0.048$). Although the measure was assessed at the forehead in this study, other findings from comparable studies also yielded similar results. However, there is no indication if the decrease in viscoelasticity is cumulative based on the years of cigarette use. Previous studies have found direct relationships between length of cigarette use and decreased viscoelasticity (Park et al., 2011; Sommers et al., 2019; Yazdanparast et al., 2019). However, in this model there is no relationship between viscoelasticity, smoking and skin injury.

Skin Injury and Skin Color

In this path analysis, the skin color L*value was significantly associated with gential skin injury prevelance but not frequency. This finding is consistent with other

research results (Baker et al., 2010; Regueira et al., 2019; Sommers, 2007; M. S. Sommers et al., 2009; M. S. Sommers et al., 2019).

The higher L* values signify ligher skin which may be more visable because of the instrumentation or touline blue, the substance used for staining the gential area (Sommers, 2007). It is worth noting that there was no other association in the path analysis to skin color with the exception of the L* value. Results may have been different if there were other body locations that were measured for skin injury. In darkly pigmented skin, other methods of assessment and inspection may better identify skin injury.

Implications for Nursing Practice

The findings of this study have important implications for nursing practice. The skin is the largest organ of the body and the primary interface between clinicians and patients. Maintaining skin integrity is a direct nursing quality care indicator (Grap et al., 2017; Meraviglia et al., 2002). This study supports the results of previous research and literature that found the interconnection between the biomechanical properties of viscoelasticity and hydration (Everett & Sommers, 2013; Regueira et al., 2019; Marilyn S. Sommers et al., 2019). In this study, viscoelasticity mediated the relationship between age and skin hydration, and age was negatively associated with viscoelasticity. These findings are all significant for nursing practice and have implications for injury prevention.

Risk reduction and risk stratification are important priorities when planning care for patients in all healthcare settings. An increased understanding of the relationships with a focus on skin integrity preservation will lead to more targeted strategic

interventions that aim to prevent and detect skin barrier disruption. The strategies include but are not limited to risk assessment screening tools and nurse driven skin care protocols, the development of instrumentation for point of care measurements, and age-specific specialized skin hygiene products.

The results also revealed several potential areas for direct interventions that will maintain the barrier integrity and ultimately enhance skin injury prevention. Because of the negative relationship between increased BMI and skin hydration found in the study, patient education that includes nutrition counseling should be explored for patients at risk for obesity. Nurse led interdisciplinary teams that include physical and occupational therapy should be incorporated into the patient's plan of care to encourage age-appropriate movement and strength training that aim to reduce or maintain body weight. Also developing or modifying the nursing admission tools to include calculated BMI scores in addition to the height and weight, may enhance the risk stratification profile to help identify patients before pressure injuries occur.

The findings related to smoking inform the nursing care of people who are aging. Nurses can provide patient education regarding smoking cessation and provide options such as the nicotine patch or gum for the patient while they are hospitalized. Nurses should also take a through smoking history during the admission assessment to further identify elderly patients who are at risk for decreased viscoelasticity. pressure injury. Those patients may need individualized plans for bathing frequency.

As the population continues to age and nurses are providing care to older patients, thorough and focused initial and periodic skin assessments should be completed with attention to continuous prevention interventions for the aging population. The nursing

focus should include interventions that lessen the effects of extrinsic factors that can contribute to skin aging. Sunscreen use, smoking cessation, and pH balanced skin products that do not strip the lipid in the stratum corneum may be indicated.

In previous work, Sommers et al. (2008) found that constitutive skin color is related to skin injury protection. The present study also that found skin color, specifically the L-value (lightness), predicted skin injury prevalence. Nurses who provide care to patients with lighter skin must recognize their increased risk for skin injury and be diligent to constantly assess for sign of disruptions of the barrier integrity. The skin assessment should include awareness of the patient's medical history, medication use and skin hygiene regimens.

Limitations of the Study

This study contributes to the knowledge of skin science, but there are several limitations. The skin injury presence and frequency outcome variable were measured by using data collected from skin in the genital-anal region. The biomechanical variables skin hydration, skin viscoelasticity and skin color data were collected at the inner thigh, an area proximal but outside of the genial-anal region. This region and the inner thigh are not completely equivalent but based on several studies and the similarities at the cellular level, the thigh is a sufficient proxy (Farage & Maibach 2006; Deliveliotou & Cretsas 2006; Elsner 1990). However, because the mechanism of pressure injury and genito-anal injury from sexual assault are different, some results may have limited generalization.

Generalization of the findings to men, older women, and groups with significant health issues or comorbidities should be viewed cautiously. The sample population consisted of only women between the ages of 21–65 who were predominately younger

without identified chronic illnesses. Quota sampling was used to obtain a representative sample of consensual control participants that were compared with a sexual assault registry. Most participants were in the 23–35-year range. This age group is generally healthy and may not experience the same skin integrity issues as an older population. The findings may not apply to middle age or older adults. Hence, a study including a more diverse age group of participants or randomly selected, age-specific groups would be more generalizable across the life span and health continuum.

No men were included in the sample; yet, apart from some structural differences, functionally, the influence of sex on skin hydration physiology may have less importance. According to a few studies, water related values such as hydration and TEWL did not differ significantly between genders (Firooz et al., 2012; Serup, Jemec, & Grove, 2006).

Several responses on the questionnaire required participants to provide self-reported answers. Answers included selecting their Fitzpatrick skin type according to the descriptions, sun exposures, and report of cigarette use. The possibility of response and recall bias was present. Respondents may have been biased when they reported on their own experiences or physical conditions in research studies (Devaux & Sassi, 2015).

There are also additional inherent limitations with a secondary data analysis study. The research question and study population selection were limited to the available data from the parent studies and there was no control of variable selection. The study was limited to variables from the original study which also limited the generalization of results. Other select variables that may influence skin barrier integrity include pH measurement, hormonal levels, and bioimpedance values (Ali & Yosipovitch, 2013; Fluhr & Elias, 2002; Rippke et al., 2002; Shu & Maibach, 2011; Tončić et al., 2018).

The Corneometer 825, Cutometer MPA580, and the Color Tec Spectrophotometer instruments were used to measure the biomechanical properties, skin hydration, skin viscoelasticity, and skin color, respectively. The existence of non-random error instrumentation was a study limitation. The potential for non-random error was reduced by selecting measurement instruments that were recognized as the gold standard based on exhaustive literature reviews and rigorous studies (Takiwaki, 1998; Takiwaki et al., 2004). Additionally, the instruments were calibrated according to the manufacturer's recommendations by the designated research team members and were periodically sent off-site for factory calibrations. Random error also occurs in instrumentation measurement. Sources of potential random error included environmental influences such as temperature, humidity, light or electrical interference, and operator error. Temperature and humidity guidelines were followed according to the study protocol to decrease the likelihood of random error. Prior to the start of the study, the research team underwent rigorous training and periodic retraining on the measurement protocols; annual validity studies were also conducted to minimize operator error as well.

The statistical method path analysis studies direct and indirect effects, it does not discover causes, but seeks to illuminate the relationships among the variables. In this secondary analysis, conclusions were made based on the association between the identified variables. Based on the conceptual model, the results indicated the model is a plausible representation of the identified relationships, but additional future research should examine the relationships by using experimental methodologies. Despite the limitations, because skin injury is a significant issue in the healthcare community, the study results are timely and relevant.

Recommendations for Future Research

The central variable of interest in this study was hydration. There are suggestions for future studies in the area of skin hydration and variables that may influence skin integrity. A future observational study could be designed to include other instrumentation that measures biomechanical factors that may influence the skin barrier such as TEWL and skin pH or explore the influence of the skin microbiome and its role in maintaining skin integrity (Fujimura et al., 2017; Honari & Maibach, 2014; Piotrowska & Czerwińska-Ledwig, 2022; Wolf & Wolf, 2012). It would also be helpful to include additional body locations to measure because of the differences in epidermal thickness all over the body to increase the generalizability of the findings.

Sommers and her team designed a skin science study and collected data that explored bioimpedance measurements and their influence on biomechanical factors which included skin hydration. The present findings of this secondary analysis have showed the influence and direct effect of age on skin integrity. Given the results of the findings and the relationships to age, additional studies including the bioimpedance measurements but with a target focus on older participants (50 and older) would be helpful. The evidence collected may help to develop and target more age-specific interventions for the older population. This study also highlights the importance of objective measurements in skin science. More research is needed to examine the use of point of care instrumentation to measure skin color and skin injury biomechanical factors in the clinical setting.

The coronavirus-2 (SARS-CoV-2) also known as COVID-19 can attack almost any organ of the body, including the largest organ, the skin. The majority of the

manifestations are usually a result of decreased vascularity to the epidermis and a disruption of the skin integrity barrier. (Cazzato et al., 2021). Research is needed to understand the cutaneous pathophysiologic processes more clearly in patients diagnosed with COVID-19 which should lead to the development of additional management strategies to prevent skin injury and maintain skin integrity during acute COVID-19 management. Research questions exploring the relationship between long COVID syndrome and skin injury prevalence and frequency should be considered. For example, should a past diagnosis of COVID-19 be considered a risk factor for increased susceptibility to skin injury or barrier disruption?

Conclusion

Skin science research continues to be an area for expansion and growth. The physiologic complexity of the skin must be considered in all aspects of evidence-based nursing care. Using data from two parent studies, this secondary analysis examined the relationships between the variables of age, BMI, sun exposure, cigarette use, and hydration in a selected female population. It examined the variability of skin injury prevalence and frequency in the selected population with hydration and also examined the relationship of the biomechanical factors skin elasticity with skin color and skin injury. A better understanding of the clinical mechanisms of how the factors interact with the epidermal barrier could support the development of additional innovative assessment tools and therapeutic interventions.

The path analysis results found that hydration was not significant in mediating the relationships between the physiologic, behavioral, and demographic factors (i.e., BMI, cigarette use, UV exposure and age) which did not support the hypothesis. The study did

yield results similar to previous skin injury research on the relationship between skin hydration and skin viscoelasticity. Also, there was a relationship between skin color (L*) and injury prevalence. These biomechanical factors work to provide significant support to the skin, enhance skin integrity and may provide protection from injury. The research results contribute to the growing body of skin science that addresses the gap in knowledge to better understand the complex relationships between several of the identified demographic, physiologic, behavioral, and biomechanic factors, and their relationship to skin injury prevalence and frequency.

Appendix A: IRB Approval Renewal

University of Pennsylvania
Office of Regulatory Affairs
3624 Market St., Suite 301 S
Philadelphia, PA 19104-6006
Phone: 215-573-2540
Fax: 215-573-9438

INSTITUTIONAL REVIEW BOARD

(Federal-wide Assurance # 00004028)

08-May-2017

Marilyn S. Sommers

ssommer@nursing.upenn.edu

PRINCIPAL INVESTIGATOR: MARILYN S SOMMERS

TITLE: Injury from Sexual Assault: Addressing Health Disparities

SPONSORING AGENCY: NATIONAL INSTITUTES OF HEALTH

PROTOCOL #: 805591

REVIEW BOARD: IRB #8

Dear Dr. Marilyn Sommers:

The above referenced protocol was reviewed and reapproved using the expedited procedure set forth in 45 CFR 46.110(b) (9), on 05-May-2017. **Approval by the IRB does not necessarily constitute authorization to initiate the conduct of a human subject research study. You are responsible for obtaining any relevant committee approvals.**

This approval is for the period 05-May-2017 to 04-May-2018.

The documents submitted with the application noted below are approved:

_Continuing Review Application, signed 4-24-17

When enrolling subjects at a site covered by the University of Pennsylvania's IRB, a copy of the IRB approved informed consent form with the IRB approved from/to stamp

must be used unless a waiver of written documentation of consent has been granted. If you have any questions about the information in this letter, please contact the IRB administrative staff. Contact information is available at our website: http://www.upenn.edu/IRB/directory. Thank you for your cooperation.

Sincerely,

IRB Administrator

Appendix B:Injury Scoring Sheet

DATE _____ PARTICIPANT #_____ EXAMINER_____ STAFF _____ Page 1 of 2

January 1, 2009; v. 5Penn

Sexual Intercourse Injury Scoring Sheet (Main Study: Exam 1 ☐ Exam 2 ☐)

Indicate areas of injury and circle location of injury on illustrations on the diagram. T=Tears; E=Ecchymosis; A=Abrasions; R=Redness; S=Swelling; 0=No Injury Noted Fill every box. Examples: 0= no injury; 2T is two tears; 1A is one abrasion. Please write clearly and complete all cells with either a number/letter or "0." If part of the GYN system has been surgically altered, missing, or cannot be visualized, indicate the missing anatomy by writing -999 in the cell.

	Visual Inspection	Colposcopy	Visual Inspection with Toluidine Blue	Colposcopy with Toluidine Blue
Oral Exam		**Take images 1-4**		
mouth	1)	2)		
Groin Exam	**Place in lithotomy**			
mons	3)	13)		
thighs	4)	14)		
Genital Exam- External		**Take images 5-11**		**Take images 12-14**
labia majora	5)	15)	23)	30)
labia minora	6)	16)	24)	31)
periurethral area	7)	17)	25)	32)
posterior fourchette	8)	18)	26)	33)
fossa navicularis	9)	19)	27)	34)
perineum	10)	20)	28)	35)
Genital Exam- Internal		**Take images 15-18**		
hymen	11)	21)	29)	36)
Speculum exam (culture after step #40)				
cervix	37)	39)		
vagina	38)	40)		
Anal Exam		**Take images 19-20**		**Take image 21**
anus – lithotomy	12)	22)		
anus – knee to chest	41)	42)	43)	44)

Did you identify other injuries, abnormalities, or alterations (piercing, tattoos, lesions) besides the TEARS? Please list type and location.

_____

Please check any and all methods that you used to identify the other injuries:

☐ Seen with visual inspection ☐ Seen with colposcope ☐ Seen with toluidine blue

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