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Water-Holding and Transport Properties of Skin Stratum Corneum of Infants and Toddlers Are Different from Those of Adults: Studies in Three Geographical Regions and Four Ethnic Groups

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Abstract:

Background/Objective: Epidermal structure, function, and composition are different in white infants and adults. We investigated whether ethnicity and location contribute to differences in functional and clinical measurements of skin barrier function during the first years of life and in adults.
Methods: Children (n = 397, ages 3–49 mos) and women (n = 117, mean age 31 yrs) were enrolled at independent centers in Beijing, China (ethnic Chinese), Skillman, New Jersey (white, African American), and Mumbai, India (ethnic South Asian). Water barrier properties of the stratum corneum were assessed using high-frequency conductance and transepidermal water loss (TEWL) on the dorsal forearm and upper inner arm. Digital imaging was used to evaluate facial erythema and scaling.
Results: Despite differences in local climate, TEWL was similar in adults. In children, conductance and TEWL decreased monotonically from age 3 months to 4 years. In children from Beijing, TEWL values were higher in both arm locations than in children in Mumbai and Skillman. No significant differences were observed in TEWL or conductance between the white and African American groups.
Conclusion: In general, TEWL and conductance were greater on the upper inner arm than the dorsal forearm. Erythema and scaling were observed most often in subjects from Beijing and most infrequently in subjects from Mumbai. Stratum corneum water barrier properties were different in children and adults.

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Although there may be differences in these properties between ethnic groups in childhood, TEWL values were similar in adults across the three geographic locations and four ethnicities.

Infant and adult skin are different at the microstructural, functional, and compositional levels (1–3). Infant skin is generally described as being softer, smoother, and more elastic than adult skin (2,4). Clinically, infant skin is prone to infection and atopic or diaper dermatitis (5,6), suggesting poorer barrier function, with the latter being the most common inflammatory skin disease in children (7).

Structural and functional properties of adult stratum corneum (SC; including water-holding and transport) can vary significantly as a function of age, race, ethnicity, body region, geographic location, skin type, and exposure (4,8–14), yet little is known about the influence of ethnicity, geography, or the environment on these properties in young children (<5 yrs). In addition, there are conflicting reports regarding differences in barrier function in dark- and light-pigmented skin types (15). Our group has shown that the architecture of the SC can vary as a function of age, body site, and ethnicity, yet meaningful differences in water-handling properties (assessed according to transepidermal water loss [TEWL] and conductance) were not observed (8).

In this study, our objective was to evaluate the water-holding and transport properties of the SC during early infancy up to the fourth year of life in children and adults from China, India, and the United States. Facial imaging was used to document two clinical signs of impaired skin barrier: erythema and flaking.

METHODS

Study Design

This international multisite study was performed at centers located in Beijing, China (January), Skillman, New Jersey (August), and Mumbai, India (March). A total of 397 infants and toddlers (3–49 mos) in Beijing, Mumbai, and Skillman and an adult female comparator group (n = 117, average age 31 yrs) from each region were enrolled, although no children ages 37 to 48 months were recruited in Beijing (Table 1). In Skillman, subjects were African American or white. At all study centers, children were stratified into one of four age categories (3–12, 13–24, 25–36, 37–49 mos). Independent ethics review boards in each location approved the study protocols, which were conducted in accordance with the ethical principles of the Declaration of Helsinki. Written informed consent was obtained from all adult subjects and from parents or legal guardians of all child subjects. Subjects refrained from using topical products and cosmetics for at least 24 hours before study evaluations. Noninvasive measurement techniques were used to assess and compare infant skin with adult skin, including TEWL, high-frequency skin conductance, and facial imaging. Average external temperature, relative humidity, and dew point over the course of the study were recorded in each study location.

TABLE 1. *Mean Temperature, Humidity, and Dew Point in Beijing, Mumbai, and Skillman and the Number of Child and Adult Participants from China, India, and the United States*

	All regions	Beijing, China	Mumbai, India	Skillman, New Jersey	
Temperature, °F/°C		31/0	84/29	77/25	
Humidity, %		31	56	62	
Dew point, °F		8	67	60	
				White	African American
Total children, n (%)	397 (77.2)	120 (75.0)	105 (72.4)	84 (82.4)	88 (82.2)
3–12 months, n (%)	143 (27.8)	59 (36.9)	43 (29.7)	21 (20.6)	20 (18.7)
13–24 months, n (%)	102 (19.8)	31 (19.4)	24 (16.6)	20 (19.6)	27 (25.2)
25–36 months, n (%)	91 (17.7)	30 (18.8)	27 (18.6)	18 (17.6)	17 (15.9)
37–48 months, n (%)*	61 (11.9)	0	11 (7.6)	25 (24.5)	24 (22.4)
Total adults, n (%)†	117 (22.8)	40 (25.0)	40 (27.6)	18 (17.6)	19 (17.8)
Total subjects, n (%)	514 (100.0)	160 (100.0)	145 (100.0)	102 (100.0)	107 (100.0)

*Child subjects in Skillman, New Jersey, were 37 to 49 months old.
†Average age 31 years.

TEWL and high-frequency conductance measurements were obtained from the dorsal forearm (DF) and upper inner arm (UIA). All measurements were performed in triplicate after a 30-minute acclimatization period in temperature- and humidity-controlled environments that were similar at each study center. Instruments of the same make and model were used at all study centers. Measurements were not taken from visibly distressed or crying infants.

Study Assessments

Water-Holding and Transport Properties TEWL was measured (VapoMeter, Delfin Technologies, Kuopio, Finland) using the closed-chamber measurement principle to determine the evaporation rate of water from skin (16). High-frequency skin conductance is indicative of the moisture content (water-holding) in the SC (17) and was measured using a skin surface hygrometer (Skicon-200EX, I.B.S, Hamamatsu, Japan).

Facial Imaging We developed a customized imaging station suitable for collecting high-resolution facial images of infants and adults. Digital images were acquired using standardized illumination in three modalities: visible, cross-polarized, and ultraviolet fluorescence (UVF). A rapid series of five images was acquired in each imaging modality. One image of the series was selected for analysis representing the best positioning (facing forward) of the participant's face within the image. This method enabled consistent collection of usable facial images. Cross-polarized images were graded for the presence of erythema and UVF images were graded for presence of skin scaling (flaking).

Statistical Analyses

Statistical analyses were conducted using JMP 8.0/9.0 software (JMP 8.0/9.0 software; SAS Institute, Cary, NC). TEWL and conductance data were fit to a standard least squares regression model using the restricted maximum likelihood estimation method for mixed models. Multiple pairwise comparisons were performed using the Tukey honest significance difference test. Categorical data are presented as means and standard errors of the mean. Frequencies of erythema and scaling of infants and adults in each ethnicity were compared, as determined using image grading, and the chi-square test was used to determine statistical significance. Significance was considered as $p < 0.05$.

RESULTS

Water-Holding and Transport Properties

Mean TEWL values at the UIA and DF of children and adults are shown in Fig. 1. Mean TEWL was similar in adults at both skin measurement sites. Overall, TEWL was greater at the UIA than the DF of children and tended to decline toward adult values at the UIA and DF as children aged. At the UIA, TEWL was significantly greater in children of all age groups than in adults of similar ethnicity. In the DF, TEWL was greater in children of all age groups than in adults in the subjects from Beijing. In contrast, DF TEWL was higher in children only in the youngest age group (3–12 mos) in whites and African Americans and was similar in children and adults from Mumbai. In

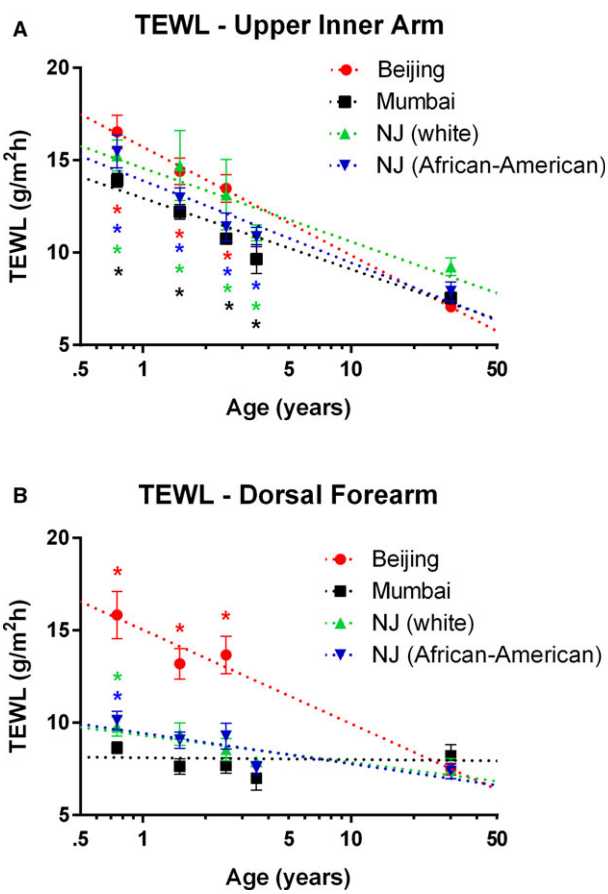

Figure 1. Transepidermal water loss (TEWL; mean ± standard error of the mean) decreased in children as a function of age at the (**A**) upper inner arm and (**B**) dorsal forearm, independent of region or ethnicity. For clarity, the age axis is shown as the log. *$p < 0.05$ versus adults from the same geographic region and ethnic group. Color of the asterisk indicates appropriate ethnic group comparison. No subjects from Beijing were recruited in the 37- to 48-month age group.

Skillman, TEWL was similar between white and African American children in each respective anatomic region and age group.

In general, UIA conductance (water-holding) values in children were also greater than those of the DF (Fig. 2). At 3 to 12 months of age conductance was greater at the UIA and DF in children of all ethnicities than in adults of each respective ethnic group. After the first year of life, conductance values were greater at the UIA in white children (13–24 and 25–36 mos) and African American children from Skillman (13–24 mos old) than in adults of similar ethnicity. High-frequency conductance in the DF of white children from Skillman (13–24 and 25–36 mos) was also significantly greater than that observed in adults. In contrast, after 1 year of life, conductance values in the DF of African American children, Indian children from Mumbai, and Chinese children from Beijing were not significantly different from those in adults of each respective ethnicity. After the age of 3 years, conductance at the UIA and DF was similar to that in adults for all ethnicities. Conductance was generally greater in African American and white children from Skillman than in children from Beijing and Mumbai.

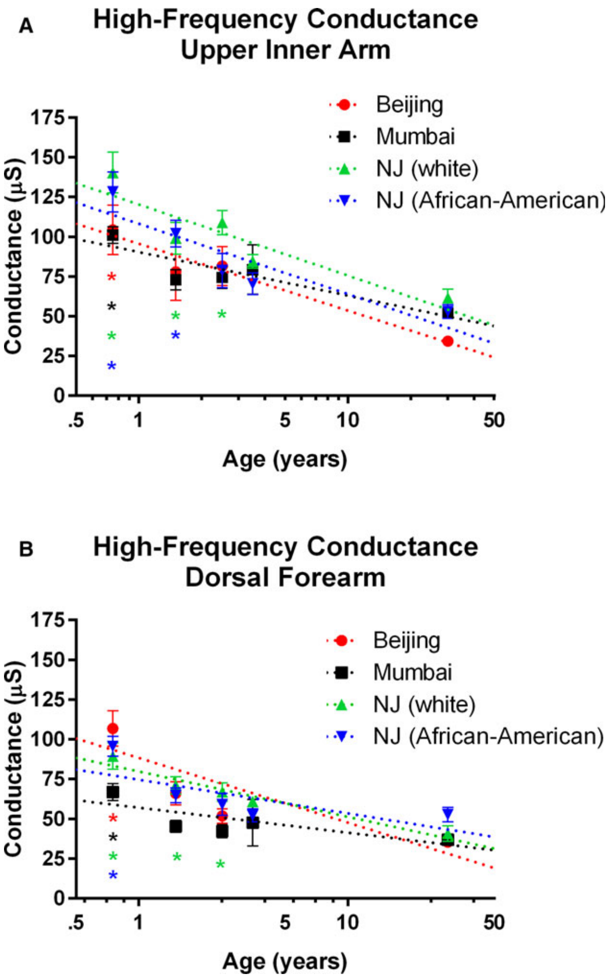

Figure 2. Skin conductance (mean ± standard error of the mean) decreased in children as a function of age at the (**A**) upper inner arm and (**B**) dorsal forearm, independent of region or ethnicity. For clarity, the age axis is shown as the log. *$p < 0.05$ versus adults from the same geographic region and ethnic group. Color of the asterisk indicates appropriate ethnic group comparison. No subjects from Beijing were recruited in the 37- to 48-month age group.

Facial Imaging

Standardized imaging was used to evaluate facial dryness and erythema in infants and adults (Fig. 3A). Cross-polarized imaging enables better visualization of erythema (Fig. 3B). These images show the visual and clinical effects of the quantitative biophysical properties measured. Scaling, or the presence of dry corneocyte flakes on the surface of the skin, is visible in UVF images owing to the strong fluorescence of dry keratin (Fig. 3C). Cross-polarized and UVF images were graded for the presence or absence of erythema and scaling, respectively, and the frequencies of any signs of erythema and scaling in infants and adults were compared (Fig. 4). Erythema was observed in the subjects from Skillman (African American and white) and Beijing. In Skillman, erythema was observed more frequently in whites than in African Americans. Erythema was more prevalent in African American adults than in African American infants ($p < 0.05$) and was trending to be more prevalent in white adults than white infants ($p = 0.10$). The frequency of erythema in infants from Beijing was similar to that in adults from Beijing. Scaling was observed only in subjects from Beijing and was more prevalent in infants than adults. In Beijing, the frequency of scaling in infants was approximately six times that in adults. Erythema was not observed in subjects from Mumbai, and scaling was observed in only 2 of 81 infants from whom analyzable images were obtained.

DISCUSSION

The primary purpose of this study was to compare SC water-holding and transport properties in children and adults in three geographic regions and four ethnicities. Several investigators have compared barrier function and water-holding and transport properties of adults of various ethnicities (4,13,18–22), but comparisons between children and adults from different ethnicities and geographic regions are sparse. To

Figure 3. Representative facial images of infants and children from (left to right) Beijing, Mumbai, and Skillman (white, African American) under (**A**) visible light, (**B**) cross-polarized visible light, and (**C**) ultraviolet excitation fluorescence mode. Cross-polarized images revealed erythema on the faces of white and Beijing infants and adults, but not African Americans or those from Mumbai. Scaling was observed through ultraviolet imaging in infants and adults from Beijing and two infants from Mumbai. Glasses were used for the ultraviolet excitation fluorescence images to protect the eyes.

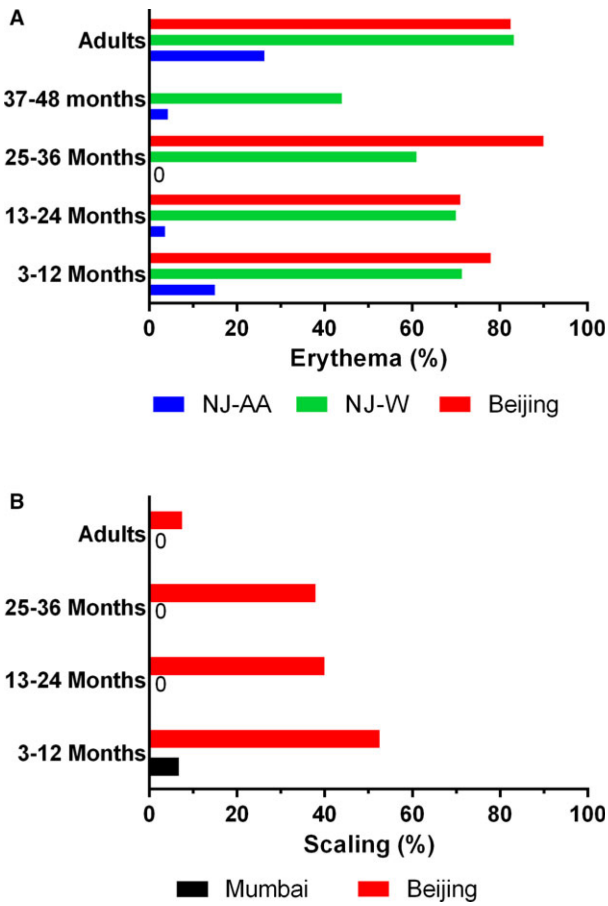

Figure 4. Percentage of subjects with (**A**) erythema and (**B**) scaling. No subjects from Mumbai exhibited erythema and no subjects from Skillman exhibited scaling. In Mumbai, only 2 of 30 (6.7%) infants ages 3 to 12 months showed evidence of scaling. No subjects from China were recruited in the 37- to 48-month age group. W, white; AA, African American.

this end, we compared functional and physiologic characteristics of child and adult SC on body sites with different exposure to the environment in three distinctive geographic regions. We found that the SC water barrier was different (higher TEWL and conductance) in children and adults, the barrier properties became more adult-like as children aged, exposure to the environment may have had a moderate effect on these properties (determined by observing differences between the unexposed UIA and more exposed DF), and water-holding and transport properties were similar in adults regardless of ethnicity or geographic region.

Our findings are consistent with previous reports (1–3,5) that found that structural and functional properties of the SC continue to mature throughout at least the first year of life. We believe our study is one of the first to report skin barrier maturation continuing into the fourth year of life. Inherent physical or morphologic variations, particularly with regard to the size of corneocytes (2,23), cells that are vital for barrier function, might explain differences between child and adult skin in part.

In general, the less exposed UIA of children had greater TEWL and high-frequency conductance than the more exposed DF. These results suggest that exposure to the environment (e.g., sun, wind) may accelerate barrier development. The finding that TEWL is similar on the DF in Indian children and white and African American children from the United States supports this hypothesis, although other factors such as anatomic differences in skin structure (14,24) and genetics that were not tested in our study cannot be excluded. Differences in skin care regimens owing to cultural habits may also contribute to the regional variations we observed. Kelleher et al (25) measured TEWL in Irish infants from birth to 6 months and noticed an association between high TEWL (75th percentile) on the second day and greater susceptibility to atopic dermatitis at 1 year. They also reported that TEWL tended to increase from 2 days after birth to 2 months, but was similar at 2 and 6 months.

Water-holding and transport properties were remarkably similar in adults from Beijing, Mumbai, and Skillman in our study. A recent study (8) by our group found that TEWL and conductance did not vary between African American and white adult women (ages 14–75 yrs), but there is inconsistency in the literature regarding whether TEWL is higher than, lower than, or the same in darkly pigmented and lightly pigmented skin types (10,13,15,18,22). Taken together, our findings and those of previous groups suggest that, by adulthood, water-holding and transport properties are similar in individuals of different ethnicities.

In Beijing, greater TEWL in the UIA and DF and a greater incidence of facial scaling was observed in children than in subjects from other regions. In Beijing, low temperature or humidity in the winter months, when the studies were performed, may have led to greater erythema and scaling on the face. During our study, the average January temperature in Beijing was 31°F, which was 53°F lower than the average March temperature in Mumbai (84°F) and 46°F lower than the average August temperature in Skillman (77°F). Beijing was also considerably drier (31% relative humidity vs 56% in Mumbai and 62% in Skillman). Given that low humidity is known to decrease water-holding capacity and cause skin dryness (26,27), we anticipate that TEWL, conductance, and the incidence of scaling may normalize in Beijing subjects during the summer months.

CONCLUSION

Water-holding and transport properties in children younger than 4 years of age are different from those of adults, independent of ethnicity or geographic region. Although age appears to have a greater influence on water-holding and transport in the SC, ethnicity, climate, and geography may also lead to differences in these properties.

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