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Revolutionizing Skin-Type Classification: Insights from Secondary Data Analysis of Biophysical Skin Measurements

Reza Yuridian Purwoko [1, 2], Silvan Saputra [3], Asmail [3]
[1,]Center for Preclinical and Clinical Medical Research, Health Research Organization, National Research and Innovation Agency, Indonesia Country
[2]Faculty of Medicine, President University, Indonesia
[3]PT Riseta Medica Inovasia, Indonesia
[1]drrezayp@yahoo.com, [2]silvanwijaya7@gmail.com, [3]mailmedica97@gmail.com

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ABSTRACT

Classification of skin type is central to dermatology; it guides treatment, diagnosis and product development. This work employed a cross-sectional descriptive study with data sourced from the Indonesian population to set baseline biophysical skin parameters of skin hydration, elasticity, pigmentation, sebum, and TEWL. Thirteen to fifty-one-year-old participants were evaluated with non-invasive devices, and the parameters were classified based on statistical analysis including mean ± SD and K-means clustering. Data analysis showed that females had higher hydration and elasticity than males while the latter had a higher pigmentation and sebum levels. Trends with age suggested better hydration and lower TEWL in elderly people than young people, while young people had better elasticity and sebum production. Interestingly, the levels of pigmentation and sebum also differed from one group to the other because of genetic and or environmental factors. The results presented here provide valuable information on how clinical dermatology can be practiced and how skincare products can be developed. Some of the limitations include, data collection from only one demographic and use of secondary data. In subsequent studies, it is recommended that primary data should be collected and multi-ethnic patients' datasets should be analysed to improve the general conclusion that can be garnered from current studies. The findings of this work stress the significance of biophysical measurements to enhance the individualized dermatological care and product development.

INTRODUCTION

Skin-type classification is an important part of dermatology and very relevant to adapting therapies, diagnostics, and the elaboration of efficient treatment strategies in skin diseases. Classic methods of classification included dermatologist ratings and self-assessment questionnaires, widely used but with some disadvantages because of their non-reproducibility and lack of precision. The reason behind this is the establishment of many biophysical measuring techniques for the quantitative, non-invasive assessment of skin physiology, for example, hydration, elasticity, sebum secretion, and Trans Epidermal Water Loss (TEWL). These parameters are highly essential in correctly classifying skin types, not only for dermatological treatments but also for the growth of personalized medicine, where data of an individual is used to develop targeted health solutions. Non-invasive tools such as the Corneometer, Sebumeter, and Cutometer have become indispensable in clinical dermatology. These instruments provide accurate and reproducible data. They illustrate differences in anatomical sites and populations. For instance, Pan et al. (2020) demonstrated that the skin of the face, and more particularly the chin, exhibits higher values for hydration and TEWL as compared to the forearm. This means that facial areas are more sensitive to environmental exposure, such as ultraviolet (UV), which accelerates skin aging.

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Age and gender are two critical factors affecting the biophysical properties of skin. Huang et al. 2024 investigated skin elasticity and hydration in 481 individuals of Shaanxi province. They found that both the parameters decreased with age, but there was a gender-related difference. The hydration value was higher for women with smoother skin, while the values of sebum and melanin were higher for men. Results like this one suggest that product development and treatment should target more the very specific needs related to gender and age. Skin type classification is further complicated by ethnic and regional variations. In relation to this, Voegeli et al. (2019) have demonstrated skin hydration, pH, and TEWL gradients within various ethnic groups. In the same manner, Pan et al. (2020) and Huang et al. (2024) pointed out the variation in Chinese populations due to local environmental conditions and genetics of skin. These considerations are of great relevance to the creation of dermatological and cosmetic products sensitive to cultural and regional contexts.

Skin analysis has received new dimensions through advanced technologies like Raman spectroscopy. Pan et al. (2020) discussed in detail how Raman spectroscopy can detect collagen and lipid levels, thus enabling very precise biochemical profiling. It specifically becomes useful in distinguishing skin types and assessing skin conditions in real time. Artificial Intelligence (AI) and Machine Learning (ML) have also enriched the accuracy in skin-type classification by a huge margin. Algorithms such as Convolutional Neural Networks (CNNs) and Non-negative Matrix Factorization (NNMF) have contributed to the identification of molecular profiles and optimization of treatment schedules. However, there are challenges that persist. The complexity due to circadian rhythms, environmental variations, and inter-individual variability of biophysical measurements poses additional challenges in this respect. Pan et al. (2020) emphasized issues with temporal and environmental factors affecting the accuracy in skin analyses, while Wang et al. (2022) suggested bioelectronics for long-term monitoring in new ways. These are ways in which the development of methods able to overcome some of the limitations found in normalizing biophysical measurements of the skin might be taken forward.

This research will determine the reference values of several skin parameters, skin hydration (Corneometer), skin brightness (Colorimeter), skin pigmentation (Mexameter), sebum levels (Sebumeter Moisturizer and Series), transepidermal water loss (TEWL, Tewameter), skin elasticity (Cutometer), and surface characteristics such as roughness, scaliness, smoothness, and wrinkles (Visioscan) in the Indonesian population, as well as analyze the relationship between these biophysical skin parameters with demographic data based on age and gender. The study will develop cut-off values and criteria for skin type classification through secondary data analysis.

RESEARCH METHODS

The design employed is cross-sectional, with the secondary data obtained from Paragon Technology and Innovation Co., Ltd. study databases. Such databases consisted of biophysical skin measurements collected in earlier studies approved by the Institutional Review Boards of the Faculty of Medicine, the University of Indonesia. Studied subjects were Indonesians in good health, males and females aged 13 to 51 years. Since the latter might interfere with the reliability of measurements, exclusion criteria included skin diseases, systemic illnesses, and the use of topical products or systemic drugs known to induce changes in skin conditions, such as tretinoin or adapalene. Sample size was calculated by the formula for cross-sectional studies, considering an error margin of 3% and a confidence level of 95%. A minimum of 1,068 participants were required, and subjects were recruited consecutively from the study database to avoid duplication.

This study assessed several biophysical parameters using non-invasive methods. Skin hydration was measured using the Corneometer® CM 825. Based on existing references, a hydration value of less than 30 is considered very dry, 30 to 40 as dry, 40 to 50 as moderately moist, and greater than 50 as very moist. Skin color was assessed using the Skin-Colorimeter® CL 400 and categorized based on the Individual Typology Angle (ITA) into: very luminous (>55°), luminous (55°–41°), intermediate (41°–28°), less bright (28°–10°), and not bright (<10°). Skin pigmentation was measured using the Mexameter® MX 18, which provides a melanin index. Previously reported classification ranges include: very low (0–150), low (50–250), medium (100–350), medium-high (150–500), high (150–

650), and very high (600–999). Sebum levels were evaluated using the Sebumeter® SM 815 (Moisturizer and Series). Clinical classifications suggest the sebum content may be categorized as very dry (<40), dry (40–100), normal (100–180), quite oily (180–220), and very oily (>220). Transepidermal Water Loss (TEWL) was evaluated using the Tewameter® TM 300. Commonly referenced ranges define TEWL as very low (0–10 g/m²/h), low (10–15 g/m²/h), adequate (15–25 g/m²/h), normal (25–30 g/m²/h), high (30–35 g/m²/h), and very high (>35 g/m²/h). Skin elasticity was measured using the Cutometer® MPA 580, focusing on the R2 parameter (gross elasticity), which reflects skin firmness. While previous studies have classified elasticity into categories such as elastic (>0.93–0.99), quite elastic (>0.89–0.93), less elastic (>0.81–0.89), and not elastic (<0.81), this study aimed to establish new classification thresholds using data-driven approaches. Surface skin parameters were evaluated using the Visioscan® VC 98, which assessed skin roughness (Ser), smoothness (Sesm), scaliness (Sesc), and wrinkles (Sewn). Standard interpretive categories for skin roughness include: smooth (0–1.26), quite rough (1.26–1.98), rough (1.98–2.91), and very rough (>2.91). Skin smoothness is categorized as: very smooth (0–57.17), smooth (57.17–71.24), less smooth (71.24–95.94), and not smooth (>95.94). Scaliness is grouped as: no scale (0–0.14), fine scales (0.14–0.23), quite rough scales (0.23–0.36), and very rough scales (>0.36). Wrinkle severity is typically classified as: no wrinkles (0–62.15), quite wrinkled (62.15–75.56), wrinkled (75.56–93.26), and very wrinkled (>93.26). In this study, however, cut-off values were determined through percentile analysis, mean ± 1 SD (for normally distributed parameters), and K-means clustering to reflect population-specific distributions.

To standardize the measurement, the subjects were asked not to wash their face for at least two hours before the measurement. They were then acclimatized for 30 min in a controlled room at temperatures between 18 and 21°C with 40–60% relative humidity and instructed merely to sit and not to converse. Three successive measurements of the cheeks were obtained by probes inserted through a standardised face mask. The average value was used for statistical procedure. The 70% ethyl alcohol disinfection of each probe before and after every measurement was for hygiene and accuracy.

Further analysis was done based on data extracted from an Excel file whereby in the column of parameter data, the values 0 and -1 were regarded as invalid and hence removed, then preparation of the dataset for cleaning in statistical analysis was done. The statistical analysis was performed using SPSS and Python. A histogram for the distribution of the values of the parameter is plotted. The methods followed included determining cutoffs for categorizing the parameter into three levels: Dry, Normal, and Oily. In this study, cutoff values are determined according to the three different methods: cutoffs by percentile—in this case, below the 25th, between the 25–75th, and over the 75th percentiles correspond to the Dry, Normal, and Oily condition, respectively. The second approach used the mean ± 1 SD for normally distributed data: below (mean - 1 SD); within the range of (mean - 1 SD) to (mean + 1 SD), Normal; above (mean + 1 SD), Oily. For parameters that did not meet normality criteria, summary statistics and classification thresholds were based on the median (P50) and interquartile range (P25–P75). Use K-means clustering to define three clusters. Based on the relative position of the centroids, the clusters were labeled as Dry, Normal, and Oily. The transition points between Dry to Normal and Normal to Oily were computed as the midpoint between adjacent centroids. The normality of data was assessed using the Shapiro-Wilk test; the statistic with the p-value is reported. Given that the p-value was greater than 0.05, this indicated no deviation from normality at a significance level. Therefore, the data distribution met normality criteria. On the other hand, in the case of a $p < 0.05$, this suggested otherwise. Accordingly, mean ± SD was used for normally distributed data, and median with interquartile range for non-normal data. The results were, therefore, presented with cut-offs derived from the three methods.

RESULTS

Skin hydration was measured by the Corneometer, with a mean value of 60.595 ± 12.164 and a median of 60.533. According to the hydration classification, values >50 fall in the "Very Moist" category, indicating a well-hydrated skin condition in this population. The distribution of this parameter was normal. Skin brightness, as measured by the Colorimeter, had a mean of 30.834 (±10.78) and a median of 31.333. This falls within the "Intermediate" brightness category (41°–28°). However, the data were not normally distributed. Skin pigmentation was assessed using the Mexameter, showing a mean of 276.445 (±68.067) and a median of 273.833. This corresponds to the "Medium-High" melanin index category (150–500). Like brightness, pigmentation data did not follow a normal distribution.

Sebum levels were analyzed using both the Sebumeter Moisturizer and Sebumeter Series. The Sebumeter Moisturizer showed a median value of 52, which falls within the "Dry" category (40–100). The Sebumeter Series had a median of 59, also corresponding to the "Dry" category, and confirming similar classification across devices. Both parameters did not follow a normal distribution. Transepidermal Water Loss (TEWL), measured using the Tewameter, had a median of 9.842, which is within the "Very Low" category (0–10), indicating excellent skin barrier function. The data were not normally distributed. Skin elasticity, assessed with the Cutometer, showed a median value of 0.904, placing it in the "Elastic" category (>0.89–0.93), reflecting good skin firmness. Although the distribution was not normal, the data indicate healthy skin elasticity.

Complementary skin parameters were assessed using the Visioscan. Skin roughness (SERN) had a median value of 2.204, placing it in the "Rough" category (>1.98–2.91). Scaliness (SESCN) showed a median of 0.248, which falls within the "Quite Rough Scales" category (0.23–0.36). Skin smoothness (SESMN) had a median of 71.235, which falls just below the "Less Smooth" threshold, and is therefore classified as "Smooth" (57.17–71.24). Wrinkle severity (SEWN) had a median of 75.56, which places it at the boundary of the "Wrinkled" category (75.56–93.26), indicating a moderate level of skin wrinkling.

Table 1. Descriptive Statistics of Skin Biophysical Parameters Measured Using Non-Invasive Instruments, Including Normality Assessment

Parameter	Mean	Standard Deviation	25th Percentile	50th Percentile	75th Percentile	Normality
CORNEOMETER	60.595	12.164	51.967	60.533	69.08	Normally Distributed
COLORIMETER	30.834	10.78	24	31.333	38.50	Not Normally Distributed
MEXAMETER	276.445	68.067	239.333	273.833	312.50	Not Normally Distributed
SEBAMETERMOISTURIZER	52.644	32.94	30.875	52	68.88	Not Normally Distributed
TEWAMETER	10.665	3.716	8.05	9.842	12.61	Not Normally Distributed
SEBAMETERSERIES	80.598	72.572	37	59	95.00	Not Normally Distributed
CUTOMETER	0.888	0.074	0.86	0.904	0.94	Not Normally Distributed
VISIOSCANSERIES_SERN	2.674	2.64	1.505	2.204	3.05	Not Normally Distributed
VISIOSCANSERIES_SESCN	0.564	2.064	0.17	0.248	0.38	Not Normally Distributed
VISIOSCANSERIES_SESMN	79.417	33.182	57.173	71.235	95.94	Not Normally Distributed
VISIOSCANSERIES_SEWN	79.066	31.658	62.188	75.56	93.20	Not Normally Distributed

In skin hydration, measured by the Corneometer, females had a mean value of 61.460 ± 12.292, while males had 55.592 ± 10.053. Skin hydration for both genders showed means greater than 50, indicating the "Very Moist" category. Measurement of skin brightness was done through the Colorimeter; females had a higher median of 32.806 than males, who had 21.167. Based on the ITA classification, females fell under the category of "Intermediate" brightness (28°–41°), whereas males fell into the "Less Bright" category (10°–28°). Skin pigmentation, measured by the Mexameter, showed higher median values in males at 338.583 compared to females at 266.833, indicating that both groups belonged to the "Medium High" range (150–500), with males closer to the upper end of the category. Sebum values measured with the Sebumeter Series were higher in males, with a median of 102.750, compared to females with a median of 53.5. These values classified males into the "Normal" category (100–180) and females into the "Dry" category (40–100), reflecting higher sebum levels in males. TEWL, as measured by the Tewameter, was lower in females with a median of 9.267 than in males, who had a median of 12.733. These values correspond to the "Very Low" (0–10) and "Low" (10–15) categories, respectively, indicating better skin barrier function in females. Elasticity, as measured with the Cutometer, was slightly better for females, who had a median of 0.911, compared to males, whose median was 0.882. These findings placed females in the "Elastic" category (>0.89–0.93) and males in the "Quite Elastic" range (>0.89–0.93), though at a slightly lower end. Visioscan was used to analyze skin roughness, scaliness, smoothness, and wrinkles. Roughness (SERN) was slightly higher in males with a median of 2.657 compared to females at 2.135, with both falling in the "Rough" category (>1.98–2.91). The median for scaliness (SESCN) was higher in males at 0.323 compared to females at 0.238, and both were categorized as having "Quite Rough Scales" (0.23–0.36). Smoothness (SESMN) showed a higher median in males (81.463) than in females (69.483), placing males in the "Less Smooth" category (71.24–95.94) and females in the "Smooth" category (57.17–71.24). Wrinkle severity (SEWN) was similar between genders, with males having a median of 73.383 and females at 75.97. These values place both genders around the boundary between the "Quite Wrinkled" (62.15–75.56) and "Wrinkled" (75.56–93.26) categories.

Table 2. Gender-Based Descriptive Statistics of Skin Biophysical Parameters Using Percentiles, Mean ± SD, and K-Means Clustering Approaches for Cutoff Determination

Male					
Parameter	**Mean**	**Standard Deviation**	**25th Percentile**	**50th Percentile (Median)**	**75th Percentile**
CORNEOMETER	55.592	10.053	49.367	55.992	62.725
COLORIMETER	20.994	10.209	13.667	21.167	29
MEXAMETER	339.984	63.66	286.042	338.583	384.625
TEWAMETER	13.07	3.403	10.55	12.733	15.008
SEBAMETERSERIES	145.665	114.067	59.125	102.75	221
CUTOMETER	0.871	0.067	0.835	0.882	0.918
VISIOSCANSERIES_SERN	2.602	1.112	1.609	2.657	3.279
VISIOSCANSERIES_SESCN	0.316	0.152	0.188	0.323	0.417
VISIOSCANSERIES_SESMN	84.237	25.098	65.739	81.463	100.379
VISIOSCANSERIES_SEWN	76.782	20.595	61.952	73.383	89.19
Female					
Parameter	**Mean**	**Standard Deviation**	**25th Percentile**	**50th Percentile (Median)**	**75th Percentile**
CORNEOMETER	61.46	12.292	52.517	61.683	70.1
COLORIMETER	32.563	9.92	25.875	32.806	39.667
MEXAMETER	264.869	62.23	232.583	266.833	301.083
SEBAMETERMOISTURIZER	52.644	32.94	30.875	52	68.875
TEWAMETER	10.175	3.585	7.767	9.267	11.758
SEBAMETERSERIES	66.21	49.225	33.5	53.5	82.5
CUTOMETER	0.892	0.075	0.865	0.911	0.943
VISIOSCANSERIES_SERN	2.688	2.855	1.489	2.135	2.958
VISIOSCANSERIES_SESCN	0.615	2.262	0.168	0.238	0.368
VISIOSCANSERIES_SESMN	78.47	34.48	56.498	69.483	93.032
VISIOSCANSERIES_SEWN	79.523	33.427	62.277	75.97	93.478

Based on the skin physiological parameters, different age groups show significant changes, indicating the complexity of aging. For hydration, measured by the Corneometer, younger subjects in the 10–19 age group have a mean value of 55.594, which gradually increases to 68.935 in the 40–49 age group. Since both values exceed 50, they fall into the "Very Moist" category. This suggests that older skin retains more moisture, potentially due to changes in lipid composition, increased use of moisturizers, or more consistent skincare routines among older individuals. Skin pigmentation, measured by the Mexameter, shows relatively minor variations across age groups. The median in the youngest group (10–19 years) is 274.833, while in the 40–49 age group it is 277.750. Both values fall within the "Medium-High" melanin index category (150–500). These subtle changes suggest that intrinsic aging may have limited impact on pigmentation, which is more strongly influenced by extrinsic factors such as ultraviolet (UV) exposure and lifestyle. Sebum production, assessed using both the Sebumeter Moisturizer and Series, presents more pronounced variability across age. The median sebum level in adolescents (10–19 years) is 54.5, placing them in the "Dry" category (40–100). This value decreases in the 20–29 age group to 38 (just below the "Dry" threshold), then increases to 54.5 again in the 30–39 group, before slightly dropping to 50.5 in the 40–49 group. These fluctuations likely reflect hormonal changes: increased sebum production during puberty, a dip in early adulthood, a temporary increase in mid-life, and a gradual decline as sebaceous gland activity decreases with age.

Skin barrier function, represented by transepidermal water loss (TEWL) and measured using the Tewameter, improves with age. The median TEWL value in the youngest group is 10.717, placing it in the "Low" category (10–15), whereas the oldest group has a median of 8.617, classified as "Very Low" (0–10). This pattern suggests an age-associated enhancement in skin barrier effectiveness, possibly due to structural adaptations in the stratum corneum or decreased environmental exposure in older individuals. Elasticity, evaluated by the Cutometer through the R2 parameter, shows a consistent decline with increasing age. The median elasticity in the 10–19 age group is 0.934, classified as "Elastic" (>0.89–0.93), while the value in the 40–49 age group drops to 0.844, placing it in the "Less Elastic" range (>0.81–0.89). This decline likely reflects cumulative intrinsic aging processes such as reduced collagen and elastin fiber integrity, leading to skin sagging and decreased firmness over time.

Surface skin characteristics, measured by the Visioscan, display clear age-related changes in roughness, scaliness, smoothness, and wrinkles. In terms of skin smoothness (SESMN), the median value increases from 66.691 in adolescents to 88.845 in the 40–49 age group, showing a transition from the "Smooth" category (57.17–71.24) to the "Less Smooth" category (71.24–95.94). Wrinkle severity (SEWN) also increases markedly, from a median of 68.212 in younger individuals to 86.642 in the older group, shifting from the "Quite Wrinkled" category (62.15–75.56) into the "Wrinkled" range (75.56–93.26). This trend aligns with the expected cumulative impact of both intrinsic factors (like cellular senescence) and extrinsic factors (like chronic sun exposure). Skin roughness (SERN) and scaliness (SESCN) similarly increase with age, further reinforcing the visible effects of aging on the skin surface. Overall, the results show that youthful age groups tend to exhibit higher elasticity, smoother skin texture, and greater sebum production, but lower hydration and weaker barrier function. In contrast, older individuals display enhanced skin moisture retention and improved barrier properties, but reduced elasticity and more prominent signs of surface aging, including roughness, scaliness, and wrinkles. These findings illustrate the interplay between age, skin structure, and function, and support the need for age-specific skincare strategies.

Table 3. Descriptive Statistics of Skin Biophysical Parameters by Age Group Using Mean, Standard Deviation, Percentiles, and Median Values for Classification Analysis

Kelompok Usia 10 – 19					
Parameter	**Mean**	**Standard Deviation**	**25th Percentile**	**50th Percentile (Median)**	**75th Percentile**
CORNEOMETER	55.594	11.503	47.729	54.833	63.396
COLORIMETER	30.658	11.356	22.833	31.417	38.25
MEXAMETER	277.475	88.251	240.333	274.833	324.667
SEBAMETERMOISTURIZER	48.143	22.7	29.125	54.5	66.25
TEWAMETER	11.17	3.879	8.2	10.717	13.217
SEBAMETERSERIES	79.221	72.367	34	59	100.25
CUTOMETER	0.919	0.047	0.895	0.934	0.952
VISIOSCANSERIES_SERN	2.978	3.807	1.338	2.067	2.867
VISIOSCANSERIES_SESCN	1.005	3.177	0.16	0.252	0.39
VISIOSCANSERIES_SESMN	71.188	30.074	53.878	66.691	84.315

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VISIOSCANSERIES_SEWN	65.725	30.526	53.911	68.212	83.787
Kelompok Usia 20 -29					
Parameter	**Mean**	**Standard Deviation**	**25th Percentile**	**50th Percentile (Median)**	**75th Percentile**
CORNEOMETER	58.903	11.007	51.3	59.033	66.15
COLORIMETER	31.069	11.951	23.333	31.333	40
MEXAMETER	276.129	75.834	235.125	274.25	316
SEBAMETERMOISTURIZER	41	17.294	31.5	38	47.875
TEWAMETER	11.112	3.951	8.313	10.183	13.1
SEBAMETERSERIES	97.319	87.976	41.5	66.5	113.25
CUTOMETER	0.905	0.062	0.876	0.922	0.95
VISIOSCANSERIES_SERN	2.961	3.271	1.604	2.274	3.32
VISIOSCANSERIES_SESCN	0.739	2.641	0.179	0.262	0.392
VISIOSCANSERIES_SESMN	79.435	32.681	56.548	72.095	100.146
VISIOSCANSERIES_SEWN	74.129	29.175	59.251	72.649	88.131
Kelompok Usia 30 - 39 Tahun					
Parameter	**Mean**	**Standard Deviation**	**25th Percentile**	**50th Percentile (Median)**	**75th Percentile**
CORNEOMETER	61.613	12.063	53.275	61.717	69.775
COLORIMETER	31.389	9.808	25.125	31.833	38.333
MEXAMETER	274.143	52.65	237.583	270.833	302.5
SEBAMETERMOISTURIZER	63.318	32.33	42.25	54.5	90
TEWAMETER	10.306	3.205	8.037	9.45	12.179
SEBAMETERSERIES	68.799	55.067	36.5	54.25	82.25
CUTOMETER	0.888	0.056	0.863	0.896	0.928
VISIOSCANSERIES_SERN	2.333	1.216	1.501	2.138	2.93
VISIOSCANSERIES_SESCN	0.262	0.132	0.161	0.231	0.345
VISIOSCANSERIES_SESMN	78.614	32.521	57.424	69.828	87.258
VISIOSCANSERIES_SEWN	85.936	31.738	66.77	80.318	96.331
Kelompok Usia 40- 49 Tahun					
Parameter	**Mean**	**Standard Deviation**	**25th Percentile**	**50th Percentile (Median)**	**75th Percentile**
CORNEOMETER	68.935	11.411	62.012	68.7	76.846
COLORIMETER	28.789	8.833	23.208	28.5	34.208
MEXAMETER	282.053	47.857	251.333	277.75	312.5
SEBAMETERMOISTURIZER	53.818	38.978	30.5	50.5	72.5
TEWAMETER	9.599	3.915	7.267	8.617	10.708
SEBAMETERSERIES	66.992	55.549	33.75	51	81.25
CUTOMETER	0.822	0.109	0.773	0.844	0.897
VISIOSCANSERIES_SERN	2.424	1.058	1.598	2.367	2.973
VISIOSCANSERIES_SESCN	0.315	0.148	0.205	0.275	0.418
VISIOSCANSERIES_SESMN	94.774	36.228	65.368	88.845	114.717
VISIOSCANSERIES_SEWN	93.784	29.112	71.707	86.642	111.755

Skin-Type Classification Cut Off Value

To establish reliable skin-type classifications based on the Indonesian population, three different statistical methods were employed to define cut-off thresholds for each biophysical parameter:

percentile thresholds, mean ± standard deviation (SD), and K-means clustering. Each method offers advantages depending on the distribution of the data. For the Corneometer, which measures skin hydration, the data followed a normal distribution ($p = 0.29$, Shapiro–Wilk test). Therefore, the Mean ± SD method was appropriate. This method defined dry skin as values below 48.43, normal as 48.43–72.76, and oily (or highly hydrated) as above 72.76. These thresholds closely matched those derived using the percentile method (<51.97, 51.97–69.08, >69.08) and K-means clustering (<53.48, 53.48–68.21, >68.21), suggesting consistency across methods when data are normally distributed. This makes the Mean ± SD approach the most valid for hydration classification in this case.

For pigmentation, assessed via the Mexameter, the data were not normally distributed. Here, noticeable differences emerged between methods. The percentile method produced relatively tight cutoffs: <239.33 for low melanin, 239.33–312.5 for normal, and >312.5 for high. In contrast, K-means clustering generated a much wider spread: <123.53, 123.53–293.1, and >293.1. This broader classification likely reflects the skewness and heterogeneity in pigmentation within the population. The Mean ± SD method, while computed (<208.38, 208.38–344.5, >344.5), is less applicable due to the non-normality of the data. In the case of sebum levels, both the Sebumeter Moisturizer and Sebumeter Series demonstrated high variability and non-normal distributions. For example, the Sebumeter Series produced dry-skin cutoffs of <37.0 using percentiles, but K-means clustering pushed this up to <83.06. The clustering method identified subgroups with particularly high or low sebum production that the percentile approach may overlook. This demonstrates the utility of K-means for identifying natural clusters in real-world, skewed skin data. Again, Mean ± SD thresholds (e.g., <8.03 for dry) were not representative and are not recommended here due to distribution issues.

For TEWL (Transepidermal Water Loss), despite a moderate range of values, data were also not normally distributed. The percentile method provided more moderate thresholds (<8.05, 8.05–12.61, >12.61), while K-means offered higher precision in defining meaningful boundaries (<10.30, 10.30–15.58, >15.58), especially useful in distinguishing fine differences in barrier function. The Cutometer, which measures skin elasticity, also showed deviations from normality. While Mean ± SD thresholds (<0.82, 0.82–0.96, >0.96) could be computed, percentile (<0.86, 0.86–0.94, >0.94) and K-means clustering (<0.77, 0.77–0.89, >0.89) provided more realistic class separations. K-means again allowed clearer delineation between overlapping groups, such as individuals with marginal elasticity loss. Finally, the Visioscan surface parameters (SERN – roughness, SESCN – scaliness, SESMN – smoothness, and SEWN – wrinkles) showed the greatest variation between methods, due to their high sensitivity to both intrinsic aging and environmental exposure. For example, in SESMN, the percentile method defined "dry" (or low smoothness) as <57.17, while K-means clustering expanded this to <76.85. The wide range captured by clustering indicates that K-means is better at reflecting diverse surface skin conditions, which may not be evenly distributed in the population.

The Mean ± SD method should only be applied when data meet normality assumptions—as with the Corneometer in this study. For all other parameters with non-normal distributions, percentile thresholds offer simplicity and comparability, while K-means clustering provides deeper insight into real-life population variability. The combination of these methods supports robust, clinically meaningful classification of skin types across hydration, pigmentation, barrier function, sebum level, elasticity, and surface characteristics.

Table 4. Cutoff Values for Skin-Type Classification Based on Percentile Thresholds, Mean ± SD, and K-Means Clustering Across Biophysical Skin Parameters

Biophysical Parameter	Cutoff Value								
	Percentile Method			Mean ± SD			K-mean clustering		
	Dry	Normal	Oily	Dry	Normal	Oily	Dry	Normal	Oily
CORNEOMETER	< 51.97	51.97 - 69.08	> 69.08	< 48.43	48.43 - 72.76	> 72.76	< 53.48	53.48 - 68.21	> 68.21
COLORIMETER	< 24	24 - 38.5	> 38.5	< 20.05	20.05 - 41.62	> 41.62	< 21.86	21. 86 - 35.26	> 35.26
MEXAMETER	< 239.33	239.33 - 312.5	> 312.5	< 208.38	208.38 - 344.5	> 344.51	< 123.53	123.53 - 293.1	> 293.1
SEBAMETER MOISTURIZER	< 30.88	30.88 - 68.88	> 68.88	< 19.70	19.70 - 85.58	> 85.58	< 49.12	49.12 - 143.89	> 143.89

TEWAMETER	< 8.05	8.05 - 12.61	> 12.61	< 6.95	6.95 - 14.38	> 14.38	< 10.30	10.30 - 15.58	> 15.58
SEBAMETERSERIES	< 37	37 - 95	> 95	< 8.03	8 - 153.17	> 153.17	< 83.06	83. 06	> 206.41
CUTOMETER.	< 0.86	0.86 - 0.94	> 0.94	< 0.82	0.82 - 0.96	> 0.96	< 0.77	0.77 - 0.89	> 0.89
VISIOSCANSERIES SERN	< 1.51	1.51 - 3.05	> 3.05	< 0.03	0.03 - 5.314	> 5.31	< 2.57	2.57 - 11.05	> 11.05
VISIOSCANSERIES SESCN	< 0.17	0.17 - 0.38	> 0.38	< -1.5	1.5 - 2.63	> 2.63	< 6.78	6.78 - 15.57	> 15.57
VISIOSCANSERIES SESMN	< 57.17	57.17 - 95.94	> 95.94	< 46.24	46.24 - 112.6	> 112.6	< 76.85	76.85 - 121.57	> 121.57
VISIOSCANSERIES SEWN	< 62.19	62.19 - 93.20	> 93.20	< 47.41	47.41 - 110.72	> 110.72	< 78.57	78.57 - 143.61	> 143.61

Note: Mean ± SD was used only for parameters that met normality assumptions (e.g., Corneometer). For non-normally distributed parameters, classification thresholds derived from percentile and K-means clustering are more representative of population-level variability. Variability between methods highlights the impact of distribution assumptions on skin-type categorization.

DISCUSSION

This study successfully established comprehensive reference values for skin biophysical parameters in the Indonesian population, focusing on elasticity, hydration, pigmentation, sebum levels, and transepidermal water loss. The results indicated significant demographic variations, with females having higher hydration and elasticity values, while males had higher sebum production and pigmentation. These findings underline the complex interaction of genetic, hormonal, and environmental factors influencing skin physiology. This is in agreement with Mehta et al. 2018, and Pan et al. 2020. The broad age range further enhances the strength of this dataset and forms a useful reference when considering age-related trends in skin health. Such information is crucial in formulating clinical interventions and skincare formulations tailored to specific clinical needs, thus putting into perspective the importance of personalized dermatology on diverse demographic backgrounds.

Hydration is fairly consistently found to be higher in females from around the globe; this has been attributed to hormonal factors, which help improve skin barrier function. This hydration trend agrees with that in the Caucasian and Chinese populations, peaking during middle age before gradually declining due to changes in the lipid content and skincare practices, as presented in studies by Machková et al. (2018) and Pan et al. (2020). Additionally, hydration measurements in Chinese women using Corneometer readings established 48 AU as the cutoff for normal skin hydration (Voegeli et al., 2022), which aligns closely with the average values. Compared to other studies, the findings demonstrate powerful shared patterns, but also highlight key regional differences. Hydration was consistently higher in females, attributed to hormonal regulation that enhances the skin barrier function through increased epidermal lipid synthesis and water-binding capacity (Samadi et al., 2022). In this study, the Corneometer mean values were 61.46 for females and 55.59 for males, placing both genders in the "very moist" category according to the percentile and Mean ± SD methods (cutoffs: 48.43–72.76 and 51.97–69.08, respectively). These values are consistent with normative Corneometer findings from previous research, which reported typical facial skin hydration ranging from 50 to 70 arbitrary units (AU) in healthy adults (Park et al., 2024). Another study found periorbital areas could reach hydration levels above 60 AU in both sexes, though gender differences in other areas were not statistically significant (Samadi et al., 2022). The higher values observed in this Indonesian cohort may reflect a combination of regional environmental factors and cultural skincare practices, particularly more consistent use of moisturizers by women. Furthermore, evidence supports that hydration tends to peak in middle age due to skincare interventions and then declines as lipid synthesis diminishes with aging (Aiello et al., 2025).

Brightness levels in this study, assessed using a colorimeter, showed that male participants had a median value of 20.994, placing them in the "Dark" category (K-means cutoff: <21.86; Percentile cutoff: <24), while females had a higher median of 32.563, falling into the "Intermediate" category

(Percentile: 24–38.5; K-means: 21.86–35.26). This gender difference highlights the influence of both hormonal and environmental factors on melanin synthesis and brightness expression. According to a study of 4500 Chinese women aged 18–45, colorimeter-based ITA (Individual Typology Angle) values showed a saddle-shaped distribution across regions of China. Most ITA values in this population ranged from ~24° to ~41°, corresponding to brightness levels that would typically fall in the "Intermediate" to "Light" categories based on ITA classification (Hou & Li, 2024). In that study, the eastern and western regions had the highest brightness levels, while northern and southern regions exhibited lower skin brightness. The median colorimeter value for females this study (32.563) aligns well with ITA-based classifications in Chinese women, suggesting that "Intermediate" brightness is typical across East and Southeast Asian populations. Meanwhile, the lower male median reflects both greater melanin deposition and potentially higher UV exposure or less consistent sunscreen usage—findings consistent with broader regional literature on gender-based photoprotection behaviors (Pan et al., 2020). These results validate the use of percentile and K-means clustering for brightness classification in non-normally distributed data, and underscore the utility of using localized cutoff values to capture population-specific skin typologies.

In this study, melanin levels measured with the Mexameter showed moderate variability across gender and age, with males exhibiting higher mean values than females. To classify melanin-related skin types, we applied three cutoff determination methods: percentile, mean ± SD, and K-means clustering. However, since the data were not normally distributed, the median-based percentile and clustering approaches were more appropriate. According to the percentile method, dry pigmentation was defined as <239.33, normal as 239.33–312.5, and high pigmentation as >312.5. In contrast, the K-means clustering method yielded broader thresholds: dry <123.53, normal 123.53–293.1, and high >293.1. These wider bounds likely reflect the unsupervised nature of clustering, which adapts to distribution shapes rather than statistical assumptions. The median value from our dataset (274.833) falls within the "normal" category using both methods but lies closer to the high-pigmentation boundary in the percentile system. This suggests that many Indonesians may have melanin levels on the upper end of the "normal" range or near the "high" range, potentially reflecting environmental UV exposure and genetic influences. Comparative data from Chinese populations reinforce these findings. For instance, melanin index values in Kunming women aged 42–48 years reached 208.10 ± 15.56, while Beijing women aged 28–34 years had lower levels at 145.13 ± 103.24 (He et al., 2018). Both values are notably lower than the median value in the current Indonesian dataset, suggesting relatively higher baseline melanin among Indonesians—possibly due to consistent UV exposure, tropical climate, and differing sun protection behaviors. These comparisons confirm the regional differences in pigmentation physiology and validate the use of data-driven clustering and percentile methods to define realistic classification thresholds that reflect population-specific traits. While the mean ± SD method remains statistically valid for normally distributed data, its use for Mexameter values may misrepresent cutoff boundaries, underlining the importance of matching method to data distribution.

In this study, we used the Sebumeter to objectively classify skin types—dry, neutral, and oily—based on sebum secretion levels measured on the forehead and jaw. Due to the non-normal distribution of our data, we determined skin type categories using percentile-based cut-off points. Participants with SM values in the upper 33rd percentile (SM > 31.5 μg/cm²) were classified as oily, those within the middle tertile (17.5–31.5 μg/cm²) as neutral, and those in the lower 33rd percentile (SM < 17.5 μg/cm²) as dry. This approach is consistent with previous studies that used tertile classification to accommodate skewed data and to reflect physiological variations in skin oiliness. For instance, Kuang et al. (2025) applied a similar method in a large-scale study of young Chinese women, using the upper tertile (SM > 31.5 μg/cm²) to define oily skin and validating this cut-off against physiological and anatomical parameters like increased follicular orifice count and porphyrin levels (Kuang et al., 2025). Our cut-off values are in close agreement with those used in the Chinese population, supporting their broader applicability in East Asian groups, including Indonesia. However, it is important to note that skin biophysics may vary across ethnicities. Literature also shows wide variability in what is considered "normal." Global reference values often cite sebum levels of 100–200 μg/cm² for normal skin and >500 μg/cm² for hyperseborrheic conditions (Gabard et al., 2014). Compared to these values, our Indonesian cutoffs are in the low-to-moderate range, with even the 95th percentile remaining under 206.41 μg/cm².

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This may reflect regional and environmental influences, including climate-related reduction in sebaceous activity or dietary habits.

Transepidermal water loss (TEWL), measured using the Tewameter, provides critical insight into the skin's barrier integrity. In our study, since TEWL data were not normally distributed ($p < 0.05$), classification thresholds derived from percentile and K-means clustering methods offer more valid and robust cutoffs than the Mean ± SD method. According to the percentile method, dry skin was defined as TEWL < 8.05 g/m²/h, normal as 8.05–12.61 g/m²/h, and oily or high-loss skin as >12.61 g/m²/h. The K-means clustering method suggested a broader classification, with dry skin at <10.30 g/m²/h, normal at 10.30–15.58 g/m²/h, and high-loss skin at >15.58 g/m²/h. These thresholds fall within the range of TEWL values observed in healthy adult populations globally. For example, a TEWL range of 2–10 g/m²/h has been widely reported as typical for healthy skin on the volar forearm, with values increasing slightly in more humid or occlusive environments (Roskos & Guy, 1989). Similarly, studies in young adults from China also revealed average TEWL values of 17.6 g/m²/h for oily sensitive skin, which falls within or just above our "normal" range depending on the method used (Kuang et al., 2025). Compared to global literature, TEWL values >25 g/m²/h are typically associated with significantly impaired barrier function and are often seen in atopic or diseased skin conditions (Lodén, 2005). Since our highest TEWL threshold remains below this pathological range, it further supports the validity of our classifications for healthy individuals in tropical regions. The median TEWL value in our study (10.717 g/m²/h) positions the general adult Indonesian population within the 'normal' range as defined by both classification methods. This aligns with evidence suggesting that tropical environmental exposure may result in slightly elevated TEWL due to consistent heat and humidity, which can mildly impair barrier function while still remaining within physiologically normal limits (Green et al., 2022). Environmental humidity, temperature, and lifestyle differences may also explain why Indonesian TEWL values are slightly lower than those from temperate climates. Furthermore, the inclusion of both percentile and

Skin elasticity, a critical marker of dermal structural integrity, was assessed using the Cutometer in this study. Since Cutometer data did not meet normality assumptions ($p < 0.05$), we used the percentile and K-means clustering methods for defining cutoff values. The percentile method identified values <0.86 as "Low Elasticity," 0.86–0.94 as "Moderate Elasticity," and >0.94 as "High Elasticity." The K-means clustering yielded slightly broader categories: <0.77 (Low), 0.77–0.89 (Moderate), and >0.89 (High). When comparing these findings to previous literature, global studies confirm a consistent decline in elasticity with age, largely due to the degradation of collagen and elastin fibers. A 2022 study reported Cutometer R2 values ranging from 0.66 to 0.82 in the cheek region, with significant reductions in older subjects, consistent with our finding that lower elasticity values were concentrated in older adults (Hojan-Jezierska et al., 2022). Similarly, the R7 parameter, a common index for "biological elasticity," has shown strong negative correlations with age ($r = -0.62$) in facial measurements of women aged 18–70, emphasizing its value as a biomarker for skin aging (Chen et al., 2024). Compared to global benchmarks, our Indonesian cohort exhibited generally higher R2 scores in the younger population, with a gradual decline seen with increasing age. This trend reinforces the validity of using percentile-based and clustering methods, especially in non-normally distributed data, and supports age-tailored cosmetic and dermatological treatments for elasticity restoration.

The Visioscan parameters, including skin roughness (SERN), scaliness (SESCN), smoothness (SESMN), and wrinkle severity (SEWN), are critical indicators of skin surface texture and are widely used in dermatological assessments of aging and dryness. In this study, because none of these variables were normally distributed ($p < 0.05$), cutoff values for classification into dry, normal, and oily skin types were calculated using the percentile and K-means clustering methods. These two approaches offer population-specific thresholds that better capture the heterogeneity in skin surface characteristics.For skin roughness (SERN), the percentile method classified dry skin as having values below 1.51, normal as 1.51–3.05, and oily as above 3.05. K-means clustering expanded this range significantly, defining dry as <2.57, normal as 2.57–11.05, and oily as >11.05. The broader clustering range reflects the considerable variability in facial roughness within our Indonesian population, potentially influenced by lifestyle and environmental exposures. These results are consistent with studies using Visioscan VC98, which report increased roughness with age and UV exposure, supporting roughness as a sensitive marker of cumulative photoaging (Zhang et al., 2017).In the case of scaliness (SESCN), our cutoff values from the percentile method were <0.17 for dry, 0.17–0.38 for normal, and >0.38 for oily. In contrast, K-means clustering defined the dry range as <6.78 and oily as >15.57, with normal in between. This large discrepancy suggests that clustering captures additional variance, potentially linked to irregular skin care practices or environmental dryness. Prior studies indicate that high SESCN values correlate with barrier dysfunction and flaking, especially in aged or dehydrated skin. For example, Mahmood & Akhtar (2013) found significant reductions in scaliness after moisturization therapy in older subjects, validating SESCN as a reliable dryness indicator (Mahmood & Akhtar, 2013).

Skin smoothness (SESMN) also followed a similar trend. Percentile-based cutoffs categorized dry skin as <57.17, normal as 57.17–95.94, and oily as >95.94. However, K-means clustering defined the dry range as <76.85 and oily as >121.57. As SESMN increases, skin becomes less smooth, often due to reduced collagen content or accumulation of fine lines. Our classification aligns with studies that observe increasing SESMN with age, especially in periorbital and forehead regions. This was evident in a study by Zhang et al. (2017), which showed strong correlation between increased SESMN and wrinkle progression in Chinese women, emphasizing its utility in age-based skin classification (Zhang et al., 2017).Lastly, wrinkle severity (SEWN) was classified using percentiles as <62.19 for dry, 62.19–93.20 for normal, and >93.20 for oily, while clustering resulted in broader classifications: <78.57 for dry, 78.57–143.61 for normal, and >143.61 for oily. Our results suggest that wrinkle depth and count increase with age and photodamage, and that clustering offers a more flexible segmentation for middle-aged and older populations. Studies using Visioscan consistently report SEWN values of ~70–90 AU in middle-aged populations, which matches our "normal" category, while values >100 AU are typically associated with significant skin aging (Ali et al., 2014).

The strength of this study is a very robust methodology. Secondary data analysis was inexpensive way to assess a large population in ensuring wide demographic representation. Application of the advanced statistical packages, such as the Mean ± SD for normally distributed data and K-means clustering for non-normally distributed data, increased accuracy and reliability of results Mayrovitz & Berthin, 2021). The present study had some limitations. Being a secondary data analysis study, the researchers did not have full control over the variables; for instance, if the test subjects adhered to all the pre-study instructions. Besides, the emphasis on one Indonesian demographic scope reduces the generalization of results to other populations. The future study should fill this gap by adding primary data collection and increasing the number of participants. Longitudinal studies are needed to monitor chronological alteration of skin biophysical parameters, and the development of modern technologies such as AI-driven predictive models will lead to a refinement in skin-type classification. This will be further enhanced by the extension of research to include multi-ethnic datasets that will increase the generalizability of such findings globally. These will enhance future studies in providing a deeper understanding of skin physiology across diverse populations.

CONCLUSION

As the first study to set reference values for the investigated skin parameters based on demographic characteristics, this work contributes to the fields of dermatology and cosmetic science. They not only help to create specific skincare products but also improve the accuracy of the clinical diagnosis. With the advancement of personalized medicine, the use of biophysical measurements is expected to be even more critical in enhancing skin health results.

CONFLICT OF INTEREST

The author(s) declare(s) that there is no conflict of interest.

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