Skin measurement devices to assess skin quality: A systematic review on reliability and validity

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Abstract

**Background:** Many treatments aim to slow down or reverse the visible signs of skin aging and thereby improve skin quality. Measurement devices are frequently employed to measure the effects of these treatments to improve skin quality, for example, skin elasticity, color, and texture. However, it remains unknown which of these devices is most reliable and valid.

**Materials and methods:** MEDLINE, Embase, Cochrane Central, Web of Science, and Google Scholar databases were searched. Instruments were scored on reporting construct validity by means of convergent validity, interobserver, intraobserver, and interinstrument reliability.

**Results:** For the evaluation of skin color, 11 studies were included describing 16 measurement devices, analyzing 3172 subjects. The most reliable device for skin color assessment is the Minolta Chromameter CR-300 due to good interobserver, intraobserver, and interinstrument reliability. For skin elasticity, seven studies assessed nine types of devices analyzing 290 subjects in total. No intra and interobserver reliability was reported. Skin texture was assessed in two studies evaluating 72 subjects using three different types of measurement devices. The PRIMOS device reported excellent intra and interobserver reliability. None of the included reviewed devices could be determined to be valid based on construct validity.

**Conclusion:** The most reliable devices to evaluate skin color and texture in ordinary skin were, respectively, the Minolta Chromameter and PRIMOS. No reliable device is available to measure skin elasticity in ordinary skin and none of the included devices could be determined to be designated as valid.

**KEYWORDS**
facial surgery, measurement tools, plastic surgery, skin quality, skin rejuvenation, systematic review
1 | INTRODUCTION

The skin is the largest and most visible organ of the human body with important protective and regulatory functions. The epidermal barrier forms the first line of defense against exogenic factors and pathogenic microorganisms. The skin also plays an important role in thermoregulation, metabolic processes, and sensory perception.\(^1\)\(^2\) Adjacent to its function, skin plays a key role in aesthetics; unfortunately, skin quality decreases over time due to aging, especially in the face. Facial aging is characterized by many changes in a broad spectrum of facial skin features, for example, pigmentation, wrinkles, and rosacea.\(^4\)\(^5\) Aging of skin can be categorized into two types of aging: intrinsic and extrinsic aging. Intrinsic aging derives from genetic and hormonal influences, whereas extrinsic aging is caused by environmental factors, such as cigarette smoke, ultraviolet radiation, or trauma.\(^6\)\(^7\) In the epidermis of the skin, aging of the face is characterized by loss of dermal mast cells and fibroblasts as well as by shortening of telomeres. In the dermis, lower levels of collagen, dysfunctional collagen, and a reduction of elastin fibers are observed.\(^4\) These cellular changes result in increased pigmentation, loss of elasticity, and formation of wrinkles over time.\(^5\)\(^7\)

Nowadays, people have become progressively concerned about their aged facial skin features. Many autologous treatments, for example, lipofilling, platelet-rich plasma, or nanofat, aim to either slow down or reverse these visible signs of skin aging and thereby improving skin quality.\(^8\) Generally, skin quality and skin quality improvement is assessed merely by visual inspection by the patient and practitioner, which is accompanied by disadvantages of interperson variability and recall-bias, making the results rather unreliable. Some clinicians determine the effectiveness of such interventions by assessing skin quality with the use of a measurement tool as, for example, tristimulus colorimetry to measure skin color, the Cutometer or Ballistometer for skin elasticity, and polarization imaging techniques to assess skin texture.\(^9\)\(^10\)\(^11\) However, it remains unknown whether these devices are accurate and dependable. Therefore, the aim of this study is to systematically search for the best-validated medical devices to assess skin quality (i.e., skin color, texture, and elasticity) in the most reliable way.

2 | METHODS

2.1 | Protocol, information sources, and search

This systematic review was performed according to the PRISMA statement.\(^12\) The databases MEDLINE, Embase, Cochrane Central, Web of Science, and Google Scholar were searched on April 16, 2019. An update search was performed on December 15, 2020. The detailed search strategy is provided in the Supplementary Content (S1).

2.2 | Eligibility criteria and study selection

Title and abstract were independently screened by two authors (M.L. and L.v.d.L.) using eligibility criteria. Full article studies were included if studies investigated the reliability and validity of medical devices assessing changes in human “ordinary” aged skin, that is, skin color, texture, or elasticity (Table 1). Studies were included if reported at least one of the following items regarding skin quality measurement devices: intraobserver reliability, interobserver reliability, interinstrument reliability, or construct validity. Studies evaluating content and criterion validity were not found. Studies assessing the quality of “diseased” skin, for example, melanoma, scars, or burn wounds, were excluded as well as animal studies. Reference lists of included studies were hand-searched for relevant studies. Disagreements were discussed during a consensus meeting with the last author (J.v.D.).

2.3 | Assessment of quality of included studies and risk of bias

The included studies were graded on quality of evidence using the Oxford Center for Evidence-Based Medicine (OCEBM) criteria.\(^13\) Disclosure agreements and funding status were reviewed for each study.

2.4 | Data extraction

Measurement devices were scored on reporting construct validity by means of convergent validity and inter or intraobserver as well as interinstrument reliability. For construct validity, the Pearson’s correlation coefficients of correlations between measurement devices were extracted and the median was depicted in a correlogram. Correlations > 0.5 or < −0.5 were considered strong. For reliability, intraclass correlation coefficients (ICCs) were reported. ICCs > 0.8 were considered good, moderate between 0.6 and 0.8, and poor < 0.6.

3 | RESULTS

3.1 | Included studies

The initial search identified 3724 publications (Figure 1). The update search yielded 621 additional publications. Hand-searching reference lists of included publications identified two additional records. After abstract screening, 4296 were excluded. Fifty studies were read in full text and assessed on eligibility criteria. Twenty-seven studies did not describe an outcome of interest and were excluded. Four publications were reviews and therefore excluded. One publication was excluded because of evaluating diseased skin. One study was excluded as it was a letter to the editor. Following full-text assessment, 18 publications were included in this systematic review.\(^9\)\(^10\)\(^14\)\(^29\)

3.2 | Study characteristics

3.2.1 | Skin color

Eleven studies assessed skin color describing a total of 16 different measurement devices analyzing 3172 subjects (Table 2).\(^9\)\(^14\)\(^22\)\(^25\)\(^30\) The largest study by Uter et al. accounted for 2287 of included...
### Table 1 Inclusion and exclusion criteria

<table>
<thead>
<tr>
<th>Inclusion criteria</th>
<th>Exclusion criteria</th>
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<tbody>
<tr>
<td>Human skin</td>
<td>Diseases and trauma affecting skin quality, for example, burn wounds, scars, and disease-caused</td>
</tr>
<tr>
<td>Medical devices assessing human skin texture, color, or elasticity</td>
<td>Reporting of intraobserver and/or interobserver reliability and/or interinstrument observer reliability and/or validity</td>
</tr>
<tr>
<td>Reporting of intraobserver and/or interobserver reliability and/or interinstrument observer reliability and/or validity</td>
<td>Case reports, conference abstracts, letter to the editor, and reviews</td>
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</table>

### Figure 1 Flow diagram of study selection

Subjects. All studies evaluated measurement devices in a predominantly Caucasian population, except for one study by Wright et al. Wright et al. researched the DRS probe and Mexameter MX 18 in a predominantly (68.5%) African American population ($n = 503$).

The two most frequently employed techniques were narrow-band reflectance spectrophotometry and tristimulus colorimetry. In narrow-band reflectance spectrophotometry, differences in red and near infrared light absorption and reflection of hemoglobin and melanin are used to measure vascularization (erythema) and pigmentation (melanin) of the skin. Included devices using reflectance spectrophotometry to assess skin color were the Mexameter MX 16 and 18, DermaLab Combo, DSM II ColorMeter, and DermaSpectrometer. In Tristimulus colorimetry, white LED is scattered in all directions and the reflected light is measured by the probe. The reflected light is analyzed and expressed in the L*a*b* color system and Individual Typology Angle index values (ITA). L* expresses brightness on the black-white axis, a* expresses erythema values on the red-green axis, and b* gives the color position on the blue-yellow axis. Instruments using Tristimulus colorimetry to measure skin color are the Minolta Chromameter CR-200 and CR-300, Colorimeter CL-400, PhotoVolt ColorWalk Colorimeter, and Visi-Chroma VC-100.
<table>
<thead>
<tr>
<th>Author, year</th>
<th>Population (n)</th>
<th>Device</th>
<th>Principle</th>
<th>Clinical parameter</th>
<th>Measurement region</th>
<th>Intervention</th>
<th>Measurement timings</th>
<th>Repetitive measurements (n)</th>
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<td>Wright et al., 2016</td>
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<td>DRS Probe MX 18</td>
<td>Diffuse reflectance spectroscopy, Narrow-band reflectance spectrophotometry</td>
<td>Melanin, erythema</td>
<td>Inner part of upper arm</td>
<td>UVB light exposure at various intensities, methyl nicotine cream or dermocorticoid cream</td>
<td>Baseline</td>
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<td></td>
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<td>Melanin, erythema</td>
<td>Inner part of upper arm</td>
<td>UVB light exposure at various intensities, methyl nicotine cream or dermocorticoid cream</td>
<td>Baseline</td>
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<td>Matias et al., 2015</td>
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<td>Antera 3D MX 18</td>
<td>Reflectance mapping with L&quot;a&quot;b&quot; color system, Narrow-band reflectance spectrophotometry, Tristimulus colorimetry with L&quot;a&quot;b&quot; color system</td>
<td>Melanin, erythema, skin color</td>
<td>The back</td>
<td>UVB light exposure at various intensities, methyl nicotine cream or dermocorticoid cream</td>
<td>Baseline, 2, 7, 12, and 14 days</td>
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<td></td>
<td>Melanin, erythema</td>
<td>The back</td>
<td>UVB light exposure at various intensities, methyl nicotine cream or dermocorticoid cream</td>
<td>Baseline, 2, 7, 12, and 14 days</td>
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<td>Baquie and Kasraee, 2014</td>
<td>12</td>
<td>Dermacatch MX 16</td>
<td>Visible-spectrum reflectance colorimeter, Narrow-band reflectance spectrophotometry</td>
<td>Melanin, erythema</td>
<td>Volar side of the forearm and the back</td>
<td>UVB light exposure, methyl nicotine cream or dermocorticoid cream</td>
<td>Baseline, 2, 7, and 14 days</td>
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<td></td>
<td>Melanin, erythema</td>
<td>Volar side of the forearm and the back</td>
<td>UVB light exposure, methyl nicotine cream or dermocorticoid cream</td>
<td>Baseline, 2, 7, and 14 days</td>
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<td>Hua et al., 2014</td>
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<td>Narrow-band reflectance spectrophotometry</td>
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<td>Face</td>
<td>-</td>
<td>Baseline</td>
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<td></td>
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<td>Melanin</td>
<td>Face</td>
<td>-</td>
<td>Baseline</td>
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<td>Gankande et al., 2014</td>
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<td>DermaLab Combo</td>
<td>Narrow-band reflectance spectrophotometry</td>
<td>Melanin, erythema</td>
<td>Head, neck, chest, back, arm, leg</td>
<td>-</td>
<td>Baseline</td>
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<td>Uter et al., 2013</td>
<td>2287</td>
<td>Minolta Chromameter CR-300 Reflektometer RM 100</td>
<td>Tristimulus colorimetry with Yxy color system Remission photometry</td>
<td>Skin color, Skin reflectance</td>
<td>Inner part of upper arm</td>
<td>-</td>
<td>Baseline</td>
<td>3</td>
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<tr>
<td>Van der Wal et al., 2013</td>
<td>50</td>
<td>Mexameter MX 18 Colorimeter CL-400 DSM II ColorMeter</td>
<td>Narrow-band reflectance spectrophotometry Tristimulus colorimetry with L<em>a</em>b* color system Narrow-band reflectance spectrophotometry and tristimulus colorimetry with L<em>a</em>b* color system</td>
<td>Melanin, erythema Skin color Skin in color, erythema melanin</td>
<td>Trunk, upper and lower extremities</td>
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<td>Baseline</td>
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<td>Chromometer</td>
<td>Principle not mentioned</td>
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<td>Baseline</td>
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<td>Barel et al., 2001</td>
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<td>Visi-Chroma VC-100 Minolta Chromameter CR-200</td>
<td>Tristimulus colorimetry with L<em>a</em>b* color system</td>
<td>Skin color</td>
<td>–</td>
<td>DHA 5% cream, methyl nicotine cream or sodium lauryl sulfate exposure</td>
<td>Baseline, 2, 4, and 24 h</td>
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<td>Kerckhove et al., 2001</td>
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<td>Minolta Chromameter CR-300</td>
<td>Tristimulus colorimetry with L<em>a</em>b* color system</td>
<td>Skin color</td>
<td>Ventral side of the forearm</td>
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<td>Baseline, 7 days</td>
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<td>Shriver et al., 2000</td>
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<td>Photovolt Color-Walk colorimeter DermaSpectrometer</td>
<td>Tristimulus colorimetry Narrow-band reflectance spectrophotometry</td>
<td>Skin color with L<em>a</em>b* color system</td>
<td>Inner part of the upper arm, forehead</td>
<td>–</td>
<td>Baseline</td>
<td>3</td>
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</table>

L*a*b* = Commission International d’Eclairage (CIE) color system. Colors are represented by three variables: L*, the lightness-darkness axis; a* the red-green axis; and b*, the blue-yellow axis.

Yxy = Commission International d’Eclairage (CIE) color system. Y value represents lightness-darkness axis.

DHA = dihydroxyacetone, product used for tanning of the skin.
3.2.2 | Skin elasticity

For skin elasticity, seven studies assessed nine types of measurement devices analyzing 290 subjects in total (Table 3).10,17,23–26 The Cutometer SEM 575 and Cutometer MPA 580 were the most frequently used devices and were assessed in four studies.10,17,24,26 The Cutometer MPA 580 is currently still available for purchase, while the Cutometer SEM 575 has been discontinued. The Cutometer uses a suction and optical measuring system to measure various parameters, such as skin distensibility (R0), gross elasticity (R2), and skin firmness (R7).26 Xu et al. assessed the 3D-DIC, which measures the displacement of skin and minor as well as major strain of skin deformation using unidirectional force.24 Other measurement devices include the BTC-2000, which measures elastic deformation of skin under subatmospheric pressure, and the Ballistometer BLS780, which uses an impact and indentation measuring system.10,25 Peperkamp et al. evaluated the Dermalab Combo to measure skin elasticity through suction.23 Hua et al. assessed the Soft Plus with an elasticity probe, which also measures skin elasticity by measuring stress under suction application.17 Lastly, in a single study, elastography with the Toshiba iAplio 900 was used to measure skin elasticity by measuring the velocity of ultrasonic waves through skin tissue.29

3.2.3 | Skin texture

Skin texture was assessed in two studies evaluating 72 subjects using three different types of measurement devices: the Visioscan VC 98, the PRIMOS, and the PRIMOSlite (Table 4).11,27,28 The PRIMOS and PRIMOSlite devices use rapid in vivo evaluation of the skin (PRIMOS) to measure surface roughness. This technique is based on the deflection of projected parallel stripe patterns on the skin due to differences in skin surface profile. The Visioscan VC 98 is a UVA-light camera that measures roughness with the Surface Evaluation for Living Skin method (SELS). The PRIMOSlite is a portable version of the PRIMOS.

3.3 | Reliability

3.3.1 | Skin color

Interobserver reliability was highest for the Minolta Chromameter CR-300 (Table 5). Van den Kerckhove et al. reported intraclass coefficients between 0.92 and 0.99 in 60 patients with measurements provided by two independent observers.21 Both Van den Kerckhove et al. and Uter et al. reported good interobserver reliability for the Minolta Chromameter as well (ICC 0.98–0.99 and 0.926–0.954, respectively).9,21 Intraobserver reliability for the Reflekтомeter RM 100 was good in a large cohort of 2287 subjects (ICC 0.938–0.946).9 In a single study of 50 participants, Van der Wal et al. assessed the interobserver reliability of the Mexameter MX 18, Colorimeter CL-400, and DSM II ColorMeter.19 The Mexameter MX 18 and DSM II ColorMeter achieved good interobserver reliability (ICC 0.92–0.94 and 0.89–0.96, respectively). The Colorimeter CL-400 achieved moderate to good interobserver reliability (ICC 0.79–0.97).22 Gankande et al. reported interobserver reliability of the DermaLab Combo assessing both melanin and erythema. ICCs for erythema were poor to moderate (ICC 0.54–0.73) and good for melanin (ICC 0.91–0.95).18 Intraobserver reliability was not tested for the Mexameter MX 18, DSM II ColorMeter, ColoriMeter CL-400, and DermaLab Combo.

3.3.2 | Skin elasticity

Intraobserver reliability was tested for the Toshiba iAplio ultrasonography (Table 5).23 Good intraclass coefficients were reported between 0.842 and 0.987 for three repeated measurements (Table 5). Interobserver reliability was not tested. The DermaLab Combo was the only device that reported interobserver reliability; intraclass coefficients were poor to moderate and varied between 0.23 and 0.76 with measurements repeated by two different observers.23

3.3.3 | Skin texture

The PRIMOS reported interobserver reliability of 0.85–0.88, with measurements by three observers in 60 patients (Table 5).28 Intraobserver reliability of the PRIMOS was 0.96–0.99.28 The Visioscan VC 98 achieved interobserver reliability of 0.95–1.00 in 12 subjects, with measurements repeated by three different observers.27 In the same study, interobserver reliability coefficients of the PRIMOSlite ranged between 0.35 and 1.00 (Table 5).27 Intraobserver reliability was not reported for the Visioscan VC 98 and PRIMOSlite.

3.4 | Validity

3.4.1 | Skin color

Darkness and erythema measurements of devices were correlated with the Fitzpatrick skin-type scale for four devices (Figure 2). Correlation for darkness values and Fitzpatrick skin-type scale score was significant for the Chromometer (R = 0.78), Colorimeter CL-400 (R = −0.68), DSM II Colorimeter (R = 0.7), and Mexameter MX 18 (R = 0.72).19,25 Three devices were assessed for correlation between erythema values and Fitzpatrick skin-type scale score. No significant correlations were found for the Colorimeter CL-400 (R = 0.12), DSM II ColorMeter (0.44), and Mexameter MX 18 (R = 0.44).19

Construct validity was tested most frequently for the Mexameter MX 18 (Figures 2 and 3). Measurements of skin darkness by the Mexameter MX 18 were significantly correlated with darkness values of the Antera 3D (R = 0.73), DRS Probe (R = 0.88), and “Soft plus” with melanin probe (R = 0.96, Figure 2).19 Measurements for skin erythema were significantly correlated with measurements of the Antera 3D (R = 0.77) (Figure 3). The previous model of the Mexameter, the Mexameter MX 16, reported significant correlations for both melanin and erythema values with the Chromometer (R = −0.77, R = 0.76), the
<table>
<thead>
<tr>
<th>Author, year</th>
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<th>Device</th>
<th>Principle</th>
<th>Clinical parameter</th>
<th>Measurement region</th>
<th>Measurement timings</th>
<th>Repetitive measurements (n)</th>
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<tr>
<td>Peperkamp et al., 2019</td>
<td>49</td>
<td>DermaLab Combo</td>
<td>Vertical suction</td>
<td>ViscoElasticity (VE), Young’s elasticity modulus (E), and skin retraction time (R)</td>
<td>Six locations on arm</td>
<td>Baseline, 45 min</td>
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<td>Xu et al., 2019</td>
<td>12</td>
<td>3D-DIC Cutometer MPA 580</td>
<td>Deformation of skin under unidirectional force Suction and optical measuring system</td>
<td>Displacement of skin, minor strain, major strain Net elasticity (R5), skin firmness (R7), total recovery (R8)</td>
<td>Volar forearm</td>
<td>Baseline</td>
<td>3</td>
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<tr>
<td>Paluch et al., 2020</td>
<td>57</td>
<td>Toshiba iAplio 900 Ultrasonograph</td>
<td>Shear wave elastography</td>
<td>Tissue strain measured by velocity of ultrasonic wave propagation</td>
<td>Face</td>
<td>Baseline</td>
<td>3</td>
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<tr>
<td>Hua et al., 2014</td>
<td>20</td>
<td>“Soft Plus” with elasticity probe Cutometer MPA 580</td>
<td>Stress/deformation of skin by suction application Suction and optical measuring system</td>
<td>Elasticity Skin distensibility (R0)</td>
<td>Face</td>
<td>Baseline</td>
<td>3</td>
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<tr>
<td>Woo et al., 2014</td>
<td>20</td>
<td>Cutometer MPA 580 Ballistometer BLS780</td>
<td>Suction and optical measuring system Impact and indentation measuring system</td>
<td>Skin distensibility (R0), return to original skin (R1), gross elasticity (R2), last maximal amplitude (R3), last minimal amplitude (R4), net elasticity (R5), viscoelasticity (R6), skin firmness (R7), total recovery (R8) Firmness and elasticity</td>
<td>Forehead, cheek, and volar forearm</td>
<td>Baseline</td>
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<td>BTC-2000</td>
<td>Deformation of skin under subatmospheric pressure</td>
<td>Elastic deformation and stiffness</td>
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<td>Ahn et al., 2007</td>
<td>44</td>
<td>Cutometer SEM 575 Moiré topography image</td>
<td>Suction and optical measuring system Visual evaluation of digital contour lines (scale 1–5)</td>
<td>Skin distensibility (R0), gross elasticity (R2), net elasticity (R5), viscoelasticity (R6), skin firmness (R7), total recovery (R8) Contour lines</td>
<td>Cheek</td>
<td>Baseline</td>
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### TABLE 4  Study characteristics of studies on skin texture measurement

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<td>Surface roughness</td>
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<td>Volar forearm</td>
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### TABLE 5  Reliability of assessed devices

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<td>Minolta Chromameter CR-300</td>
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<td>Uter et al., 2013</td>
<td>Minolta Chromameter CR-300</td>
<td>0.926–0.954&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>Van der Wal et al., 2013</td>
<td>Mexameter MX 18 Colorimeter CL-400 DSM II ColorMeter</td>
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<td>Gankande et al., 2014</td>
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<td>Elasticity</td>
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<td>Paluch et al., 2020</td>
<td>Toshiba iAplio 900 Ultrasonograph</td>
<td>0.842–0.987</td>
</tr>
<tr>
<td>Peperkamp et al., 2019</td>
<td>DermaLab Combo</td>
<td>–</td>
</tr>
<tr>
<td>Texture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kottner et al., 2012</td>
<td>Visioscan VC 98 PRIMOS&lt;sup&gt;St&lt;/sup&gt;</td>
<td>–</td>
</tr>
<tr>
<td>Bloemen et al., 2011</td>
<td>PRIMOS</td>
<td>0.96–0.99</td>
</tr>
</tbody>
</table>

<sup>a</sup>The reliability of the Minolta Chromameter CR-300 was tested in smaller cohorts of 190, 10, and 8 patients.

Dermacatch (R = 1, R = 1), and the DermaSpectrometer (R = 0.53, R = 0.81).

The Minolta Chromameter CR-200 showed significant correlation with darkness values of the Visi-Chroma VC-100 (R = 0.93). The Minolta Chromameter CR-300 had significant correlation with the Reflekтомeter RM 100 (R = 0.69). However, both the Minolta Chromameter CR-200 and CR-300 have currently been discontinued, while the newer model Chromameter CR-400 has not yet been evaluated in clinical research.

#### 3.4.2  Skin elasticity

Ahn et al. reported significant correlation between Cutometer values and the values on a digital grading scale, the so-called Moiré topography (R = 0.67).<sup>26</sup> Moiré topography is a digital program which generates contour lines on a digital photograph of a patient. An evaluator clinically rates these contour lines from 1 to 5 for decreasing skin elasticity.<sup>26</sup> Moreover, the Cutometer reported significant correlations with measurements of the Soft plus with elasticity probe and the 3-DIC (R = −0.64 and 0.57, respectively, Figure 4).<sup>24</sup> No significant correlation was found between the Cutometer MPA 580 and the Ballistometer BLS780 for gross elasticity (R2), net elasticity (R5), and skin firmness (R7) parameters (R < 0.5).<sup>10</sup>

#### 3.4.3  Skin texture

The measurements of the Visioscan VC 98 and PRIMOS<sup>St</sup> were not significantly correlated, so no construct validity could be determined.<sup>27</sup>
3.5 | Conflict of interest/risk of bias

All 18 studies were level of evidence III studies.\textsuperscript{9,10,14-29} Eight out of 18 articles did not report funding and conflict of interest.\textsuperscript{15-17,21,24,26,27,29,30} However, one of these studies was performed by a contract research organization, which developed the investigated device.\textsuperscript{15} Three articles reported no conflict of interest, but did not elaborate on funding.\textsuperscript{11,19,25} Seven articles disclosed funding.\textsuperscript{9,10,14,18,20,22,23} In six of these studies, no conflict of interest was apparent. In a single study, three authors were involved with the company that developed the investigated measurement device.\textsuperscript{20}

4 | DISCUSSION

This review aimed to determine the most reliable and validated available medical devices for assessing skin color, texture, and elasticity. The most reliable medical device for skin color evaluation is the Minolta Chromameter CR-300 due to good interobserver, intraobserver, and interinstrument reliability in a Caucasian population. The most reliable medical device for skin texture evaluation is the PRIMOS device with excellent intra and interobserver reliability. For the evaluation of skin elasticity, no device could be designated as superior because none of the included devices reported at least both intra and interobserver reliability. Unfortunately, none of the reviewed measurement devices for skin color, elasticity, or texture could be designated to be superior in terms of validity based on construct validity. Yet, many other critical aspects of validity that are needed to determine which measurement device is best valid, were missing in all included studies. These aspects are content and criteria validity, responsiveness, and interpretability of the included devices. Hence, none of the devices to measure skin color, texture, or elasticity could be selected as valid.

Validity can be divided into construct validity, content validity, and criterion validity. Construct validity by means of convergent validity is the degree to which different devices that should theoretically measure the same construct are actually correlated. The convergent validity of the included measurement devices of skin color and elasticity demonstrated that the majority of these devices measure similar constructs, for example, the Mexameter MX 18 measurements showing significant correlation with the Antera 3D, DRS Probe, and “Soft plus” with melanin probe. When multiple devices interlink, a web of correlations or correlogram can be constructed. Theoretically, this increases the probability that what is being measured is valid. A limitation of the use of convergent validity is that a correlation between devices does not automatically mean that either of the devices actually measures the intended parameter. For example, in case of skin color, van der Wal et al. correlate measurements of the Mexameter MX 18, Colorimeter CL-400, and DSM II ColorMeter to the Fitzpatrick skin phototyping scale. The Fitzpatrick scale is widely used to categorize skin color but was originally developed to select the correct dose of photochemotherapy in the treatment of psoriasis.\textsuperscript{33} The parameters assessed in the Fitzpatrick scale are, therefore, primarily focused on predicting the reaction of the skin to ultraviolet light. This scale might, therefore, not
reflect all facets of the parameter “color” like undertones, redness, or evenness in color. Therefore, it is not surprising that Van der Wal et al. did not find a significant correlation between erythema values of the aforementioned included measurement devices and Fitzpatrick skin-type scale score. This highlights the shortcomings of the use of only construct validity.

Content validity specifies the degree to which assessment instruments are representative of and relevant to the targeted construct these devices are designed to measure. For content validity, a measurement device should measure all aspects of a construct, for example, skin color. By default, a measurement device cannot factor all different nuances of skin color. Criterion validity refers to the degree to which a measure relates to an outcome. Generally, this concerns comparing the instrument under assessment to a different instrument that has been considered as valid, that is, the “gold standard.” To date, there is no gold standard for the evaluation of skin color, elasticity, and texture, making criterion validity assessment impossible.

Besides different validity criteria, a measurement device is only useful in clinical practice when it detects clinically meaningful changes in the measured parameter (responsiveness). Responsiveness can be evaluated by correlating changes in the values of measurement devices following intervention to clinical subjective scores. These scores could be questionnaires or scales documenting the perceived benefit of the intervention from the patients’ and clinicians’ viewpoint. The evaluation of responsiveness is critical to determine whether a device can detect clinically meaningful changes in skin quality. Moreover, a clinical understanding of what the quantitative values or changes in value of the device mean (interpretability) should also be investigated. None of these parameters were reported in any of the included studies.

Our analysis focuses on devices that evaluate the outcome of interventions that influence skin quality. Therefore, in the context of evaluation of outcomes of clinical interventions like lipofilling, we propose the following criteria for a measurement device to be considered valid. First, a device should be reliable, meaning both inter and intraobserver reliability should be tested and ICC should be at least 0.8. Second, a measurement device should be able to detect a clinically relevant change of a measurable parameter. Clinical relevance can be detected by correlating changes in measurement values to clinical results assessed by practitioners or subjects following cosmetic intervention like lipofilling. These patient- or practitioner-reported outcome measures could, for instance, be blinded clinical photographic analyses, or satisfaction as measured with the FACE-Q questionnaires. Reproducibility, responsiveness, and interpretability are critical aspects for a device to be considered valid and reliable.

5 | CONCLUSION

The most reliable devices to evaluate skin color and texture in ordinary aged skin were, respectively, the Minolta Chromameter and PRIMOS. No reliable device is available to measure skin elasticity in ordinary aged skin and none of the included devices could be determined to be designated as valid. Independent responsiveness and interpretability research of available devices is needed to determine which
device measures skin quality in the most reliable and reproducible way.

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CONFLICT OF INTEREST
The authors have no conflict of interest to disclose.

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