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ORIGINAL ARTICLE

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Validation of the elastic angle for quantitative and visible evaluation of skin elasticity in vivo

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Abstract

Background: Reduction in skin elasticity due to aging causes skin sagging and wrinkles. Although there are various objective and reliable techniques for measuring skin elasticity, it is difficult to obtain a visual representation of skin elasticity with them. Therefore, we developed a novel device, the Swing anglemeter, and analyzed its effectiveness for measuring skin elasticity of the cheek.

Materials and Methods: Forty-five healthy Korean women (age, 23-60 years) participated. The Swing anglemeter works by dropping a rubber ball on a subject's cheek, which draws a curve as it collides with the cheek. After recording the movement of the ball using the slow-motion function on a mobile phone, we defined the maximum angle at which the ball bounces off the skin as the elastic angle, using frame-by-frame video analysis. Changes in the elastic angle were assessed according to age, and correlation with the Ballistometer® results (Dia-stron Ltd., Andover, UK) was analyzed for validation.

Results: Elastic angles differed significantly ($P < .001$) according to age. A negative correlation was found between the elastic angle and age ($r = -.799$, $P < .001$). Compared with the Ballistometer® measurements, the elastic angle was negatively correlated with alpha ($r = -.570$, $P < .001$); it was positively correlated with the mean coefficient of restitution and area ($r = .602$, $P < .001$ and $r = .535$, $P < .001$, respectively).

Conclusion: The elastic angle is a useful parameter for reflecting skin elasticity, both quantitatively and visually. Our method can help subjects understand their skin elasticity status. Therefore, we expect the device will be utilized in various fields within the cosmetic industry.

KEYWORDS

age, Ballistometer®, correlation, quantitative evaluation, skin, visible evaluation

1 | INTRODUCTION

The mechanical properties of human skin are important for maintaining the structure of the epidermis, dermis, and subcutaneous tissue and normal function.[1,2] One of the mechanical properties of the skin is elasticity, which is related to the stability of the elastin and collagen fiber network within the skin.[3] However, when skin aging progresses due to extrinsic factors, such as ultraviolet or air pollution exposure, and intrinsic factors, such as biological or genetic properties, the elastin and collagen fibers become degraded and denaturized.[4-6] Owing to this phenomenon, skin elasticity decreases, which causes skin sagging and wrinkles. Therefore, measurement of elasticity is important to assess skin status and to maintain skin beauty, and over the past decades, many physicists and bioengineers have developed various techniques for evaluating the physical properties of skin in vivo, including the evaluation of skin elasticity.[7]

The most commonly used device to measure skin elasticity is the Cutometer® (Courage+Khazaka Electronic GmbH, Koln, Germany), which provides non-invasive evaluation using the principle of negative pressure. Of the many R parameters (R0-R9) of the Cutometer®, R2, R5, and R7 are the most commonly utilized parameters for the analysis of skin elasticity as a ratio of relaxation to deformation.[8,9] The Ballistometer® BLS780 (Dia-stron Ltd.) evaluates skin elasticity by assessing the interaction between dropping and bouncing a mass on the skin surface.[10,11] The higher the mass bounces from the surface of the skin, the better the skin's elasticity.[12,13] These devices for measuring skin elasticity have the advantage of providing a reliable, professional, and objective assessment. However, because the results are mostly presented numerically and graphically, and not visually, it is difficult to monitor changes in elasticity during skin aging or with the use of skincare products, unlike wrinkles and pigmentation. This limitation often makes it difficult for subjects to comprehend the benefits of the assessment. Ahn et al suggested a quantitative and visual evaluation method, Moiré topography, based on the interference pattern of images so that subjects can easily perceive changes in their skin elasticity.[14] Nevertheless, there have been few related studies, and thus, additional evaluation methods and scientific validation are required.

This paper deals with the development of a device that can measure skin elasticity using an angle and the characteristics of the measured value. An angle is the shape formed by two lines in Euclidean geometry, which can be checked visually as the degree when an object moves while drawing a curve. The purpose of this study was to validate the reliability of our evaluation method of measuring skin elasticity with the elastic angle by analyzing the correlation between the results of this method and that of the Ballistometer® (Dia-stron Ltd.), which has a similar measurement principle. Based on this validation, our technology may improve the limitation of the Ballistometer®, which is that it is difficult for subjects to perceive the status or change in elasticity easily because the movement of a mass in the Ballistometer® cannot be seen and the result is provided only numerically. Considering the fact that the higher the elasticity of the surface, the farther the colliding object bounces off skin, we assumed that the better the skin elasticity, the greater the elastic angle.

2 | MATERIALS AND METHODS

2.1 | Study design and participants

Forty-five healthy Korean women (age, 23-60 years) were recruited and divided into four groups based on age: 20-29 (n = 11), 30-39 (n = 14), 40-49 (n = 10), and ≥50 (n = 10) years. Subjects who were pregnant or receiving skin therapy in clinics were excluded. All participants were equilibrated to 22 ± 2°C and 45 ± 5% relative humidity in a room for a minimum of 30 minutes prior to testing. All subjects were informed of the study details and were asked about collagen supplementation, which could affect their skin elasticity, and we confirmed that no subjects were taking it. Then, they signed an institutional review board-approved consent form prior to participation in the study (approval number: LGHH-20201029-AA-02).

2.2 | Device used to measure skin elasticity: the Swing anglemeter

The Swing anglemeter was manufactured by LG Household and Healthcare (Seoul, South Korea). It measures 22 cm wide × 30 cm long × 46 cm high, and has a holder for fixing the ball and an electromagnet switch for dropping the fixed ball on the top of the device. A round hole measuring 7 cm in diameter is located on the right side for exposing the subject's cheek. When the user drops the ball by operating a switch while the subject's cheek is in close contact with the hole of the Swing anglemeter, the ball draws a curve and collides with the subject's cheek. The ball was made from rubber, and a fishing line was connected to the ball (Figure 1A).

2.3 | Parameter for the quantitative and visible evaluation: the elastic angle

The measurement was taken from the cheek. When the user dropped the ball by operating a switch while the subject's cheek was in close contact with the hole of the Swing anglemeter, we defined the maximum angle at which the ball hit and bounced off the skin as the elastic angle (Figure 1C). Before the measurement, a tripod and iPhone Special Edition (SE) (Apple Inc, Cupertino, CA, USA) were installed in front of the device to check the change in the movement of the ball (Figure 1B), and the ball's motion was precisely recorded using the slow-motion function (240 frames per second) of the iPhone SE (Video S1). Measurements of the elastic angle were repeated three times for each subject in a manner that captured the screen that the ball bounced off maximally by detailed frame-by-frame analysis of the video, and it was calculated quantitatively using ImageJ software (National Institutes of Health).

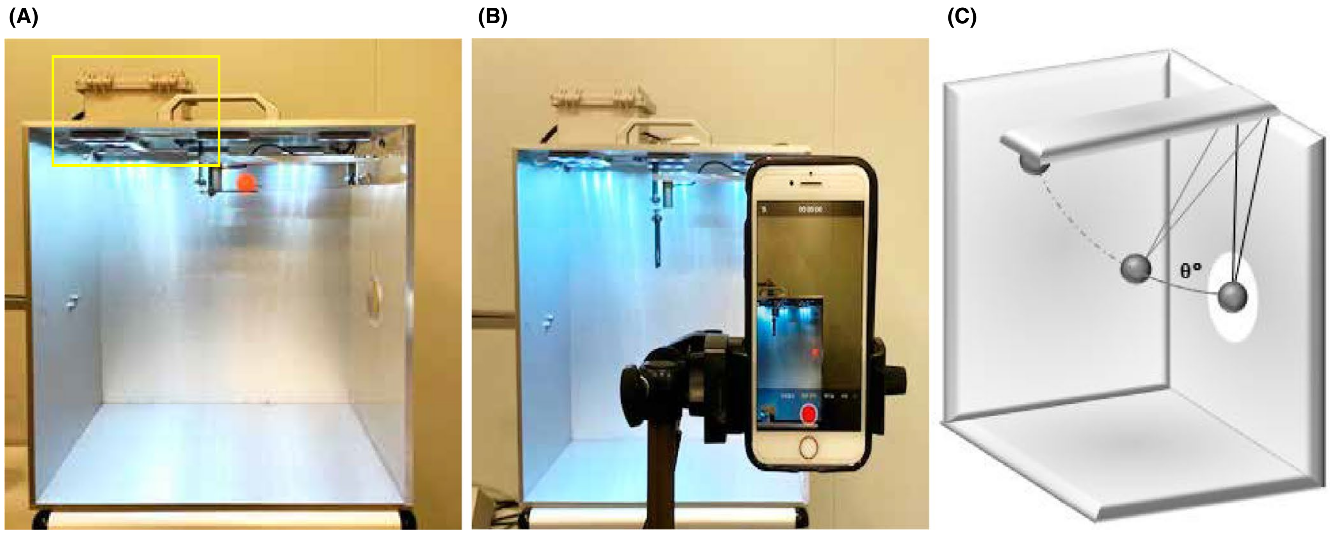

FIGURE 1 Device used to measure skin elasticity based on the elastic angle. (A) The user drops the ball by operating a switch, and the ball draws a curve and collides with the subject's cheek on the right side (yellow rectangle: electromagnet switch). (B) A tripod and iPhone SE are installed in front of the device to record the movement of the ball. (C) The schematization for the elastic angle, the maximum angle at which the ball bounces. SE, Special Edition

TABLE 1 Parameters calculated by the Ballistometer®

Parameter (unit)	
Alpha (AU)	Rate of exponential decay
CoR 1, 2, 3 (AU)	Coefficient of restitution for the first, second, and third bounces
Mean CoR (AU)	Average of CoR 1, CoR 2, and CoR 3
Area (mm^2)	Area under the curve
K (mm)	Start height
Indentation (mm)	Indentation depth

Abbreviations: AU, arbitrary unit; CoR, coefficient of restitution.

2.4 | Reliability validation of the elastic angle using the Ballistometer®

As a reference for the validation of the elastic angle, skin elasticity was also measured with the Ballistometer® BLS780 (Dia-stron Ltd.), which evaluates mechanical properties using the interaction of dropping and bouncing a mass on the skin surface.[10,11] The Ballistometer® was originally developed for testing homogeneous, hard industrial materials. However, it is also used to evaluate mechanical properties, including the elasticity of the skin.[2] Using the Ballistometer®, the following five parameter values were calculated automatically using a software included with the Ballistometer®: indentation, K, alpha, coefficient of restitution (CoR), and area (Table 1). Woo et al reported that the mean CoR and area are useful parameters to evaluate skin elasticity of the forehead, cheek, and volar forearm using the Ballistometer®.[10] Langton et al confirmed that there were significant differences in three parameters (alpha, mean CoR, and area) measured at the forearm in young and old subjects.[13] Therefore, we selected alpha, mean CoR, and area as measurement parameters for our validation, and after measuring the elastic angle of the cheek with the Swing anglemeter, the same site was then measured three times in the same manner.

2.5 | Statistical analysis

After all measurements were completed, we analyzed the change in the elastic angle by age group using one-way analysis of variance (ANOVA), and Bonferroni correction was used for post hoc analysis. We also analyzed the correlation between the elastic angle and age, and between the elastic angle and Ballistometer® measurements using the Pearson correlation coefficient for validation. All data were statistically analyzed using IBM SPSS Statistics for Windows, version 25 software (IBM Corp.), and P-values <.05 were considered significant.

3 | RESULTS

3.1 | Changes in the elastic angle by age group

Table 2 shows the elastic angle measurements by age group. Changes in the elastic angle were found to be significantly different according to age using one-way ANOVA ($P < .001$), and the post hoc analysis using Bonferroni correction revealed statistically significant differences between the 20s and 40s age groups, the 20s and ≥50s

TABLE 2 Changes in the elastic angle by age (N = 45)

Age groups (y)	20s (n = 11)	30s (n = 14)	40s (n = 10)	≥50s (n = 10)	*P*-value
Elastic angle (degree)	23.87 (±1.48)	21.82 (±1.32)	20.10 (±2.25)	17.77 (±2.35)	<.001*

Note: Results are expressed as the mean (±standard deviation).
Changes in the elastic angle by age group were analyzed using one-way analysis of variance, and the differences between the groups were statistically significant.
**P* < .001.

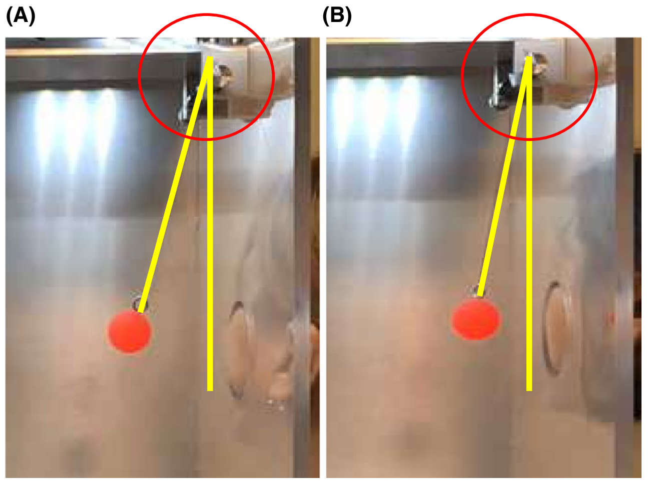

FIGURE 2 Images for comparison of the elastic angle in two different age groups. (A) The elastic angle (angle in red circle) of the 20s group is significantly higher than that of the ≥50s group (B). Results were statistically compared using post hoc analysis with Bonferroni correction (*P* < .001)

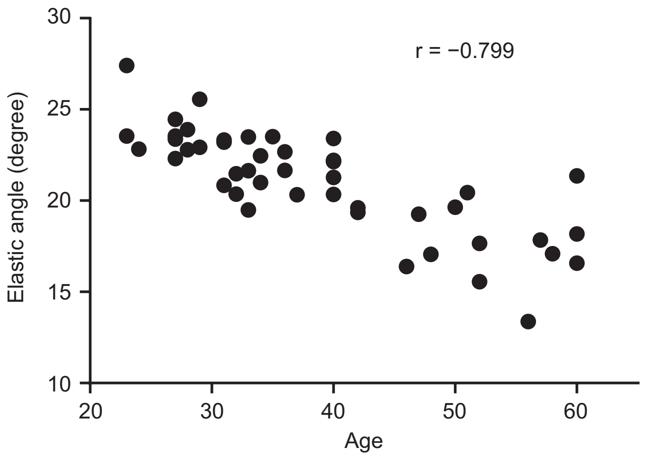

FIGURE 3 Correlation between age and the elastic angle. The distribution between age and the elastic angle is negatively and significantly correlated. (Pearson correlation coefficient: $r = -.799$, $P < .001$)

age groups, (Figure 2), the 30s and ≥50s age groups, and the 40s and ≥50s age groups. The higher the age, the lower the elastic angle.

3.2 | Correlation between age and the elastic angle

Figure 3 displays the distribution of the elastic angle by age and the correlation coefficient between age and the elastic angle. A significant negative correlation was found between these parameters ($r = -.799$, $P < .001$). The maximum elastic angle was 27.4 degrees in the 20s age group (at 23 years of age), and the minimum elastic angle was 13.3 degrees in the 50s age group (at 56 years of age), based on the result that the elastic angle was dependent on age.

3.3 | Correlations between three parameters of the Ballistometer® and the elastic angle

Figure 4 shows the distributions of the elastic angle by the calculated values from the Ballistometer® and the correlation coefficients between them. The elastic angle correlated negatively with alpha; however, it correlated positively with mean CoR and area. In addition, all correlation coefficients were significant (alpha: $r = -.570$, $P < .001$; mean CoR: $r = .602$, $P < .001$; area: $r = 0.535$, $P < .001$).

4 | DISCUSSION

Skin elasticity is closely related to skin aging, and it affects the clinical and histological appearance of skin.[15,16] Although there are many objective and accurate techniques for measuring skin elasticity, it is difficult for individuals to perceive the changes in their elasticity status because skin elasticity cannot be visualized like wrinkles and different pigmentations.[14] Therefore, we considered another evaluation method to overcome this limitation and developed a device, the Swing anglemeter, for measuring skin elasticity using the elastic angle. As a result of measuring and analyzing the elastic angle after dividing the subjects into four age groups, we found that it decreased significantly as age increased, and its distribution by age showed a negative and significant correlation. This finding is consistent with results of many studies showing that as skin aging progresses, skin elasticity decreases due to weakness of the skin structure, which is related to the degradation or denaturation of elastin and collagen fibers.[5,6] Further, analysis of the correlation between the elastic angle and the three parameters of the Ballistometer®, similar to that in Woo et al's study,[10] confirmed the possibility that the elastic angle can also be utilized for quantitative evaluation of skin elasticity.

To validate the reliability of the elastic angle, it was compared with the Ballistometer® measurements. Among the values calculated by the Ballistometer®, alpha showed a significant negative correlation with the elastic angle, and mean CoR and area showed

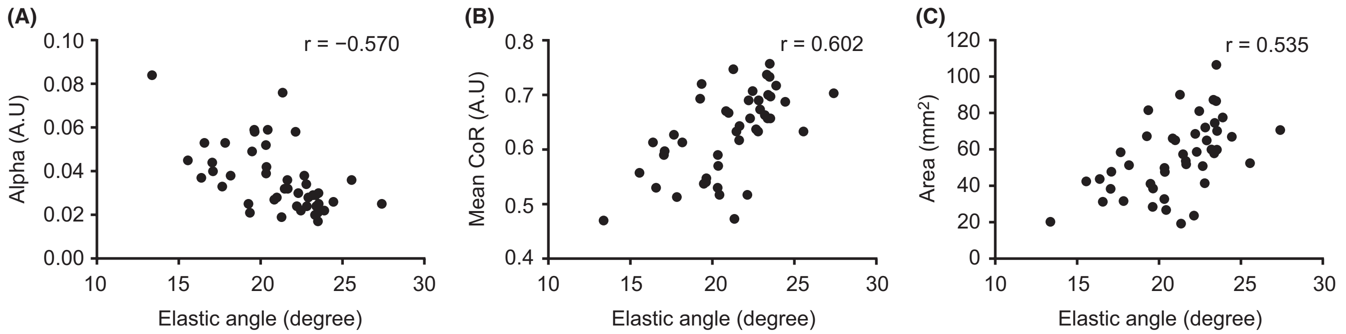

FIGURE 4 Correlations between the calculated Ballistometer® measurements and the elastic angle. The distributions between the elastic angle and Ballistometer® measurements show a negative correlation with (A) alpha and positive correlations with (B) mean CoR and (C) area. All correlation coefficients are significant (Pearson correlation coefficient: $r = -.570$, $P < .001$ for Alpha; $r = .602$, $P < .001$ for mean CoR; $r = .535$, $P < .001$ for area). CoR, coefficient of restitution; AU, arbitrary unit

a significant positive correlation with the elastic angle. Alpha, mean CoR, and area are the rates of energy damping, the bounce height relative to the start height, and the area between the bounce profile and the zero datum, respectively (Table 1).[10,13,17] These results mean that the elastic angle is closely related to the characteristics of the three parameters; however, more scientific research is needed to determine the related mechanism and cause. Based on our study's results, we suggest using an evaluation method with validated reliability, such as ours, by which subjects can easily perceive their elasticity status via movement of a ball because it is difficult to assess elasticity visually with the Ballistometer® even though it is an excellent device for measuring elasticity.

5 | CONCLUSIONS

In conclusion, we demonstrated that the elastic angle is a useful parameter for quantitative evaluation and visual presentation of skin elasticity, based on our finding that it can reflect skin elasticity with increasing age and its correlation with the Ballistometer® measurements. The Swing anglemeter is optimized for measuring elasticity of the cheeks. Thus, the device and evaluation method will need to be improved to visually measure elasticity not only of the cheeks but also of other areas in further research, such as evaluation of elasticity at other body regions. Subjects can more easily perceive changes in their skin elasticity with use of the elastic angle, and this method will be informative in skin beauty and health fields. In the future, it is expected that the elastic angle will be useful in various fields within the cosmetic industry.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTION

JM performed the research, analyzed the data, and wrote the paper. MK designed the device for research. ETK, JML, NGK, and SGP contributed to drafting the manuscript or revising it critically for important intellectual content.

DATA AVAILABILITY STATEMENT

The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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