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Sleeping Position and Periocular Asymmetry: A three-dimensional Stereophotogrammetry Study

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Minghui Wang
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1. Gutachter: Universitätsprofessor Dr. med. L. M. Heindl
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Dedication

To my family and friends

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Abbreviation

3D	Three-dimensional
SSP	Sleeping Side Preference
Non-SSP	Non-Sleeping Side Preference
MRD 1	Margin Reflex Distance 1
MRD 2	Margin Reflex Distance 2
PFH	Palpebral Fissure Height
PFW	Palpebral Fissure Width
UEC	Upper Eyelid Crease Distance
PE	Pupil-to-Eyebrow Distance
OSA	Ocular Surface Area
WPA	Whole Periocular Area
2D	Two-dimensional
En	Endocanthion, inner commissure of the palpebral fissure
Ex	Exocanthion, outer commissure of the lower and upper eyelash roots of the palpebral fissure
Pc	Pupillary center
Ps	Palpebrale superioris, point vertical to Pc at the upper palpebral margin on the lash roots
Pi	Palpebrale inferioris, point vertical to Pc at the lower palpebral margin on the lash roots
Lm	Medial corneoscleral limbus point horizontal to pupillary center
Ll	Lateral corneoscleral limbus point horizontal to pupillary center
FPs	Point vertical to Pc at the lid fold superioris
EPs	Point vertical to Pc at the lower margin of the eyebrows
Lm’	Point vertical to Lm at the upper palpebral margin on the lash roots
Lm’’	Point vertical to Lm at the lower palpebral margin on the lash roots
Ll’	Point vertical to Ll at the upper palpebral margin on the lash roots
Ll’’	Point vertical to Ll at the lower palpebral margin on the lash roots
Um	Middle point between En and Lm’ at the upper palpebral margin on the lash roots

Um’	Middle point between En and Lm” at the lower palpebral margin on the lash roots
Ul	Middle point between Ex and Ll’ at the upper palpebral margin on the lash roots
Ul’	Middle point between Ex and Ll’’ at the lower palpebral margin on the lash roots
EEn	Point vertical to En at the inferior margin of eyebrows
EEx	Point vertical to Ex at the inferior margin of eyebrows
EExl	Point vertical to Ex at the inferior margin of eyebrow in the lateral review
EUm	Point vertical to Um at the inferior margin of eyebrows
ELm	Point vertical to Lm at the inferior margin of eyebrows
ELl	Point vertical to Ll at the inferior margin of eyebrows
EUl	Point vertical to Ul at the inferior margin of eyebrows
VAM	VECTRA Analysis Module

1. Summary

Previous studies have validated the accuracy of three-dimensional (3D) stereophotogrammetry in facial imaging. Although several studies have reported the associations between sleep posture and various periocular changes, the specific effects remain underexplored. In this study, we quantitatively assessed the effects of sleeping position preference on periocular asymmetry using 3D stereophotogrammetry.

A total of 110 Caucasian volunteers were involved in this prospective study, who were divided into the Sleeping Side Preference (SSP) group and the Non-Sleeping Side Preference (Non-SSP) group, due to their different sleeping position behaviors. The VECTRA M3 3D Imaging System was used to obtain standardized 3D facial photographs. The Margin Reflex Ristance1(MRD 1), Margin Reflex Distance 2 (MRD 2), Palpebral Fissure Height (PFH), Palpebral Fissure Width (PFH), Upper Eyelid Crease Distance (UEC), Pupil-to-Eyebrow Distance (PE), Ocular Surface Area (OSA), and Whole Periocular Area (WPA) were measured by using VAM software. The asymmetry index was computed, and comparisons between the groups were performed to evaluate the impact of sleeping position on periocular asymmetry.

Our results showed that 58 participants belonged to the SSP group and 52 were in the Non-SSP group. The groups did not differ significantly in terms of gender, average age, or average sleep duration. Within the SSP group, the preferred sleeping side revealed decreased MRD 1 (5.072±0.787 vs. 5.915±0.845, P<0.001), PFH (10.192±1.140 vs. 10.676±1.186, P<0.001), and OSA (2.307±0.637 vs. 2.383±0.626, P=0.045). There were no significant differences in MRD 2 (p = 0.520), PFW (p = 0.950), UEC (p = 0.107), PE (p = 0.413), and WPA (p = 0.437) between the preferred and non-preferred sleeping sides in the SSP group. Statistically significant differences were observed between the two groups in the asymmetry index of MRD 1 (P < 0.001), PFH (P =0.006), and OSA (P = 0.013). The comparisons between the two groups revealed no significant differences in the asymmetry index for MRD 2 (P = 0.719), PFW (P = 0.077), UEC (P = 0.658), PE (P = 0.165), or WPA (P = 0.257). No statistically significant association was found between the asymmetry index and average sleep duration.

This was the first time that 3D stereophotography was used to quantitatively assess the impact of different sleeping positions on periocular asymmetry. Our results demonstrated that side sleeping was associated with increased upper eyelid asymmetry, primarily due to a reduced upper eyelid height. From a preventive perspective, the result may be informative for people to further increase awareness of the potential impact of long-term side sleeping and take corresponding preventive measures. For patients with periocular asymmetry, the result may be informative for them to slow down the progression of periocular asymmetry caused by sleeping position. In addition, the current study can also serve as a reference for ophthalmic surgeons in the process of preoperative counseling, in order to make a customized treatment plan in accordance with the patients' sleeping position habits, aiming at better surgical results as well as increasing patient satisfaction. Incorporating sleep posture evaluation into clinical consultations may represent a simple yet effective strategy for managing periocular asymmetry.

2. Zusammenfassung

Frühere Studien haben die räumliche Genauigkeit der dreidimensionalen (3D) Stereofotogrammetrie in der Gesichtsanalyse bestätigt. Obwohl mehrere Studien über Zusammenhänge zwischen Schlafposition und verschiedenen periokulären Veränderungen berichtet haben, sind die spezifischen Auswirkungen bislang wenig erforscht. In dieser Studie haben wir die Auswirkungen der bevorzugten Schlafposition auf die periokuläre Asymmetrie mittels 3D-Stereofotogrammetrie quantitativ untersucht.

An dieser prospektiven Studie nahmen insgesamt 110 kaukasische Freiwillige teil, die aufgrund ihres unterschiedlichen Schlafpositionsverhaltens in die Gruppe mit bevorzugter Schlafseite (SSP) und die Gruppe ohne bevorzugte Schlafseite (Non-SSP) eingeteilt wurden. Standardisierte 3D-Gesichtsfotografien wurden mit dem 3D-Bildgebungssystem VECTRA M3 aufgenommen. Die folgenden Messwerte wurden mit der VAM-Software ermittelt: Margin Reflex Distance 1 (MRD 1), Margin Reflex Distance 2 (MRD 2), Lidspaltenhöhe (PFH), Lidspaltenbreite (PFW), Abstand der Oberlidfalte (UEC), Pupillen-Augenbrauen-Abstand (PE), Augenoberflächenfläche (OSA) und der gesamte periokuläre Bereich (WPA). Es wurde ein Asymmetrieindex berechnet, und die beiden Gruppen wurden hinsichtlich des Einflusses der Schlafposition auf die periokuläre Asymmetrie verglichen.

Unsere Ergebnisse zeigten, dass 58 Teilnehmer zur SSP-Gruppe und 52 zur Nicht-SSP-Gruppe gehörten. Die Gruppen unterschieden sich nicht signifikant hinsichtlich Geschlecht, Durchschnittsalter oder täglicher Schlafdauer. Innerhalb der SSP-Gruppe zeigte die bevorzugte Schlafseite eine verringerte MRD 1 (5,072±0,787 vs. 5,915±0,845, P<0,001), PFH (10,192±1,140 vs. 10,676±1,186, P<0,001) und OSA (2,307±0,637 vs. 2,383±0,626, P=0,045). Es gab keine signifikanten Unterschiede bei MRD 2 (p = 0,520), PFW (p = 0,950), UEC (p = 0,107), PE (p = 0,413) und WPA (p = 0,437) zwischen der bevorzugten und der nicht bevorzugten Schlafseite in der SSP-Gruppe. Statistisch signifikante Unterschiede zwischen den beiden Gruppen wurden beim Asymmetrieindex von MRD 1 (P < 0,001), PFH (P = 0,006) und OSA (P = 0,013) beobachtet. Die Vergleiche zwischen den beiden Gruppen ergaben keine

signifikanten Unterschiede beim Asymmetrieindex für MRD 2 (P = 0,719), PFW (P = 0,077), UEC (P = 0,658), PE (P = 0,165) oder WPA (P = 0,257). Es wurde kein statistisch signifikanter Zusammenhang zwischen dem Asymmetrieindex und der durchschnittlichen Schlafdauer der Patienten festgestellt.

Dies ist die erste Studie, die die Auswirkungen unterschiedlicher Schlafpositionen auf die periokuläre Asymmetrie mittels 3D-Stereofotografie quantitativ bewertet hat. Unsere Ergebnisse zeigen, dass das Schlafen auf der Seite mit einer erhöhten Asymmetrie des oberen Augenlids verbunden ist, was hauptsächlich auf eine verringerte Höhe des oberen Lids zurückzuführen ist. Aus präventiver Sicht könnten diese Ergebnisse hilfreich sein, um das Bewusstsein für die möglichen langfristigen Auswirkungen einer bevorzugten Seitenlage zu schärfen und entsprechende Maßnahmen zu ergreifen. Für Patienten mit periokulärer Asymmetrie können die Ergebnisse dazu beitragen, die durch die Schlafposition verursachte Progression zu verlangsamen. Darüber hinaus kann diese Studie als Referenz für ophthalmologische Chirurgen bei der präoperativen Beratung dienen, um individualisierte Behandlungspläne unter Berücksichtigung der Schlafgewohnheiten zu erstellen, mit dem Ziel einer besseren Operationsergebnisse und höherer Patientenzufriedenheit. Die Integration der Schlafposition in die klinische Beratung könnte eine einfache, aber effektive Strategie zur Behandlung periokulärer Asymmetrie darstellen.

3. Introduction

3.1 Facial Asymmetry and Periocular Asymmetry

Facial asymmetry, defined as an imbalance between the two sides of the face, is common and may range from minor, physiologically normal variations to clinically significant deformities.[1]

In fact, perfect facial symmetry is virtually nonexistent in the general population. Minor asymmetries are found in more than 90% of healthy individuals, and about 10% to 20% of people have asymmetries that are visible to the naked eye, even without specialized measurements or imaging.[2] Since facial symmetry plays a major role in how we perceive beauty and attractiveness, it’s a topic of interest not only in medicine but also in fields like psychology and cosmetic science.[3]

The jawline and mandible, particularly within the lower third of the face, are most frequently involved.[4] Periocular asymmetry is also common and thought to result from differences in muscle tone or eye dominance. Although asymmetries in the midface or nose occur less frequently, they tend to be more noticeable when present.[5,6]

As for the demographic factors that are related to facial asymmetry, age plays a significant role, as asymmetry often becomes more pronounced over time due to the loss of soft tissue, changes in bone structure, and the persistent effects of gravity. Although research generally shows no major difference in the actual amount of asymmetry between men and women, people may perceive it differently depending on gender.[7] Additionally, ethnic differences in facial structure can affect both the extent of asymmetry and how it’s interpreted, making it harder to compare across different population groups.[8]

Etiologically, facial asymmetry may stem from congenital disorders such as hemifacial microsomia, craniosynostosis, and cleft lip or palate[9]; from developmental anomalies like asymmetric skeletal growth or malocclusion; and from acquired causes, including trauma, tumors, and neuromuscular conditions like Bell’s palsy. Over time, soft tissue variation and facial asymmetry can also develop gradually as a result of long-term lifestyle, environmental, and physiological forces. For instance, habitual side sleep, chewing predominantly on one side, past tooth extractions, and long-term use of dentures are associated with variation in facial symmetry. Issues that manifest in early life—such as growing up in an adverse environment—may also contribute by affecting nutrition, medical attention, and developmental stability in general. [10,11]

When facial asymmetry becomes severe, its range goes beyond that of aesthetics to overall physical and mental health. Several studies have shown that severe asymmetry of the face is linked to an increased susceptibility to psychological disorders like depression and anxiety.[12,13] Individuals with lower facial symmetry are at higher risk of displaying neurotic behaviors such as tension and anxiety, while those with higher symmetry are found to fare well in various mental health scales. Furthermore, individuals with more symmetrical facial features tend to exhibit better health and longer lifespan.

The periocular area, consisting of the eyelids, the eyebrows, and the immediate tissues, is of special significance in the preservation of facial symmetry as well as aesthetic harmony.[14,15] In addition to its aesthetic function, the periocular region also supports essential visual functions. Abnormalities in this region can also lead to functional issues, including upper visual field constriction, ocular surface irritation, epiphora, and exposure keratopathy.[13,16,17] Given the high mobility of the lower face due to frequent expressions, asymmetries in the periocular area tend to be more noticeable when the face is at rest.[18] This highlights the clinical importance of evaluating periocular soft tissue asymmetries.

3.2 Sleeping Position

Among the possible contributors, sleep position has appeared as a cause of facial asymmetry in recent years.[19] Most individuals spend approximately one-third of their lifetime sleeping, and for many adults, side-sleeping is the preferred posture.[20] Some studies have shown that about 50% of adolescents tend to sleep predominantly on one side.[21,22] Over time, this consistent position may lead to mild but noticeable asymmetry, particularly in areas as sensitive and structurally dynamic as the eyes and surrounding tissues.

More and more evidence is emerging that habitual side-sleeping can have long-term effects on periocular and facial anatomy. Clinical observations have linked habitual side-sleeping with eyelid laxity, lower eyelid ectropion, and progression of keratoconus.[20,23,24]Some researchers have pointed out that these findings suggest that prolonged mechanical compression on one side of the face during sleep may gradually alter soft tissue and even underlying bone structures. These deformations do not occur in the short term, but rather accumulate over years or even decades of repeated stress, and their mechanisms involve complex biomechanical processes.[25]

The impact of sleeping posture on periocular symmetry and tissue structure is gradually gaining attention. Although this chronic deformation is difficult to completely avoid, it is hoped that by raising public awareness, encouraging the adoption of a more neutral supine sleeping posture, and developing auxiliary devices to reduce facial pressure, the structural changes caused by sleeping posture may help mitigate the structural changes associated with sleep posture.

3.3 Three-dimensional (3D) Stereophotogrammetry

3.3.1. Principles

Three-dimensional (3D) photogrammetry refers to a group of techniques that use multi-angle photography to capture the morphology of facial soft tissues, reconstruct 3D facial models, and quantify distances, angles, surface areas, and volumes via specialized software.[26,27]

Three-dimensional photogrammetry employs various technical paradigms, with stereophotography currently being the most widely used in clinical practice. This process captures images from various angles—either with multiple cameras or by repositioning a single camera—to obtain different perspectives of the same object. The images are subsequently processed with computer algorithms to produce point cloud and texture data, which are used to construct a 3D model through computational alignment and stitching.[28-31]

3.3.2. Commonly Used Devices

There are currently several types of 3D stereophotogrammetry imaging systems, such as portable cameras (e.g., Vectra H1/H2), fixed-position systems (e.g., 3dMDface), and full-body imaging systems (e.g., Vectra XT).[32-36] The accuracy and reproducibility of these devices have been validated, making them suitable for a wide range of clinical applications.[37-40]

3.3.3. Clinical Applications

3D stereophotogrammetry has been extensively used to evaluate facial morphology in healthy subjects who have not undergone surgical procedures. Key research focus areas are age-related facial change, ethnic variation, and aesthetic profiling.[41] Age-related studies often evaluate changes such as ptosis, eyelid laxity, tear trough depression, midface sagging, and deepening of the nasolabial folds.[42] 3D imaging enables these features to be quantified and compared across different age groups. Furthermore, the average-face modeling technique can visually display trends of aging with a clear understanding by registering composite faces of multiple age groups.[43,44] Ethnic studies, while less dominant than 3D studies, are highly entrenched within two-dimensional (2D) studies, with rich research opportunities for expansion.[15,18,45,46] Other than that, 3D assessment for pleasing facial attributes has been included to construct aesthetic norms and contribute to objective cosmetic surgical planning.[47]

In clinical practice, 3D photogrammetry is employed to evaluate surgical and non-surgical treatments of the face. The technique accurately measures morphologic changes along linear, volumetric, and angular axes. It has been applied to estimate outcomes of maxillofacial surgery, oculoplastic surgery, rhinoplasty, treatment of wrinkles, cryolipolysis, and injectable aesthetic treatments.[48-53] Its capacity to estimate surgical outcomes and analyze postoperative results with accuracy is a significant advantage, far surpassing that of traditional 2D imaging in illustrating soft tissue movement. The technique provides accurate metrics, thereby making it one of the most sophisticated facial evaluation tools nowadays.[28]

3.3.4. VECTRA M3 3D Imaging System

For this study, the VECTRA M3 3D imaging system (Canfield Scientific, USA) was employed, providing a geometric resolution of 1.2 mm.[31] The system simultaneously acquires high-resolution images from multiple angles, reconstructs detailed 3D facial models, and has increasingly become a prominent alternative to traditional 2D photography and manual caliper measurements in recent years.[40,54,55] Imaging is rapid (lasting only milliseconds), resistant to subject movement, and computer-automated. Its software can perform quantitative measurements of linear, angular, areal, and volumetric face parameters with high accuracy, non-invasiveness, and good reproducibility, which is well-suited for detecting subtle changes in facial morphology.[56,57]

3.4 Current Research and Limitations

Although some studies have investigated sleep-related eyelid conditions like floppy eyelid syndrome, the link between habitual sleep position and periocular symmetry remains understudied. [58-60] This is especially true in healthy individuals who show no obvious ocular symptoms but may exhibit subtle posture-related structural changes due to longstanding habitual pressure. A clearer understanding of how common activities like sleep position affect periocular symmetry carries both clinical and aesthetic implications for diagnosis and treatment.

Moreover, earlier studies of sleep posture and periocular asymmetry were carried out mostly using 2D image assessment, with no systematic exploration of its effect within the whole periocular region. Such methods generally demand high levels of subject compliance and are prone to errors of measurement.[61,62] Therefore, the development of newer, more precise, and reproducible measurement techniques is essential for assessing facial morphology—especially in the periocular region, where structural differences are often subtle.[28,37,63-65]

Periocular asymmetry can be influenced by the skeletal system or soft tissue, or both. It has to be mentioned that mild asymmetries are not usually apparent at clinical examination.[66] Thus, clinical examination of facial asymmetry involves the application of precise and quantitative measuring techniques. Compared to traditional direct anthropometry, 3D stereophotography requires less subject cooperation and is faster. Unlike typical 2D anthropometry, 3D techniques are more precise and can calculate surface area and volume differences.[67] To help fill this research gap, our study employs 3D quantitative measurement techniques to systematically examine how sleep posture affects periocular asymmetry.

3.5 Aims

This study aims to objectively measure the periocular area with a 3D stereophotogrammetry system. Our goal is to detect how sleeping position preference affects periocular symmetry and provides informative data for subsequent cosmetic surgery and periocular deformation assessment.

4. Materials and Methods

4.1 Participants

Our study recruited Caucasian volunteers at the University Hospital of Cologne. This research adhered to the Declaration of Helsinki and its subsequent revisions. Approval was obtained from the University of Cologne Ethics Committee (No. 24-1372_1), and participants gave written informed consent. Exclusion criteria included individuals <18 years old; had sleep apnea, congenital periocular asymmetry, or a history of facial trauma, facial surgery, laser resurfacing, or cosmetic facial injections; had any periocular or periorbital disease, strabismus, or nystagmus; or had any other of the habitual or environmental factors previously reported to contribute to facial asymmetry, including predominantly chewing on one side, prior tooth extractions, long-term denture use, or growing up in a low socioeconomic environment.

4.2 Clinical Data Collection

Basic information was collected, including age, gender, and average sleep duration. Participants who met the inclusion criteria were asked to complete a questionnaire regarding their typical sleeping position, categorized as predominantly on the right side, predominantly on the left side, both sides, predominantly prone, or predominantly supine. Participants who primarily slept on one side, either right or left, were classified as the Sleeping Side Preference (SSP) group, while those who slept equally on both sides or exclusively in the supine position were identified as the Non-Sleeping Side Preference (Non-SSP) group. Individuals who consistently slept on their stomachs were excluded, as they might not be able to identify a preferred side. Participants who were unsure of their usual sleep position were also excluded from the study.

4.3 3D Stereophotography

The VECTRA M3 3D Imaging System (Canfield Scientific, Inc., Parsippany, NJ, USA) was used to capture standardized 3D facial photographs. (Figure 1) Daily camera calibration was performed, and all images were captured by an experienced operator according to the manufacturer’s instructions. The photographs were captured in a consistent clinical photography room with controlled lighting, excluding natural light, and patients removed glasses, masks, facial coverings, and makeup before imaging.

Figure 1. The 3D imaging system[91]

4.4 3D Measurement

To ensure reliability, two trained raters independently performed image measurements and analyses. On each 3D photograph, bilateral periocular landmarks were identified and marked, including En, Ex, Ps, Pc, Pi, Lm, Ll, FPs, EPs, Lm’, Lm’’, Ll’, Ll’’, Um, Um’, Ul, Ul’, EEn, EEx, EExl, EUm, ELm, ELl and EUl, as illustrated in Figure 2 and detailed in Table 1.

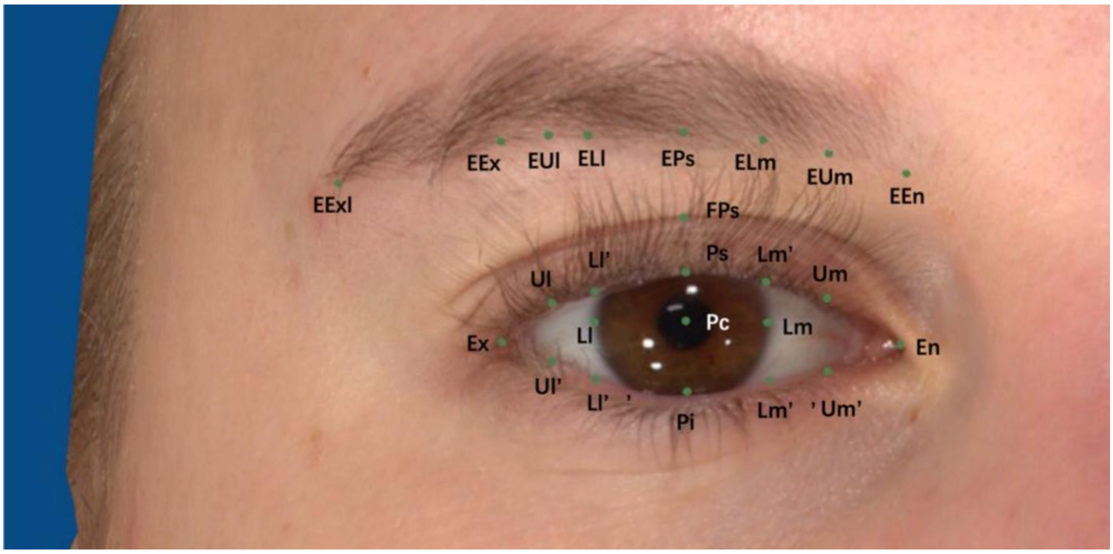

Figure 2. The standardized landmarks of three-dimensional evaluation. (The frontal view of the periocular region)

Table 1. Definitions of anthropometric landmarks and parameters in the periocular region.

Abbreviation of landmarks	Definition
En	Endocanthion, inner commissure of the palpebral fissure
Ex	Exocanthion, outer commissure of the lower and upper eyelash roots of the palpebral fissure
Pc	Pupillary center
Ps	Palpebrae superioris, point vertical to Pc at the upper palpebral margin on the lash roots
Pi	Palpebrae inferioris, point vertical to Pc at the lower palpebral margin on the lash roots
Lm	Medial corneoscleral limbus point horizontal to pupillary center

Ll	Lateral corneoscleral limbus point horizontal to pupillary center
FPs	Point vertical to Pc at the lid fold superioris
EPs	Point vertical to Pc at the lower margin of the eyebrows
Lm’	Point vertical to Lm at the upper palpebral margin on the lash roots
Lm’’	Point vertical to Lm at the lower palpebral margin on the lash roots
Ll’	Point vertical to Ll at the upper palpebral margin on the lash roots
Ll’’	Point vertical to Ll at the lower palpebral margin on the lash roots
Um	Middle point between En and Lm’ at the upper palpebral margin on the lash roots
Um’	Middle point between En and Lm” at the lower palpebral margin on the lash roots
Ul	Middle between Ex and Ll’ at the upper palpebral margin on the lash roots
Ul’	Middle point between Ex and Ll’’ at the lower palpebral margin on the lash roots
EEn	Inferior margin point of eyebrow vertical to En
EEx	Point vertical to Ex at the inferior margin of eyebrows
EExl	Point vertical to Ex at the inferior margin of eyebrow in the lateral review

EUm	Point vertical to Um at the inferior margin of eyebrows
ELm	Point vertical to Lm at the inferior margin of eyebrows
ELl	Point vertical to Ll at the inferior margin of eyebrows
EUl	Point vertical to Ul at the inferior margin of eyebrows

Modified from Guo Y et al.[68]

Additionally, the Margin Reflex Distance 1 (MRD 1), Margin Reflex Distance 2 (MRD 2), Palpebral Fissure Width (PFW), Palpebral Fissure Height (PFH), Upper Eyelid Crease Distance (UEC), Pupil-to-Eyebrow Distance (PE), Ocular Surface Area (OSA), and Whole Periocular Area (WPA) were measured using VECTRA Analysis Module (VAM) software. (Figure 3 and Table 2) [21,68,69] The asymmetry between the right and left periocular regions was assessed by calculating absolute difference values. The asymmetry index was calculated as: (absolute bilateral difference / smaller value of the two sides) × 100%. [12,70,71] Then, we calculated the differences between the preferred and non-preferred sleeping sides in the SSP Group. We further computed and compared asymmetry indices across the two groups to assess how sleeping posture influences periocular asymmetry.

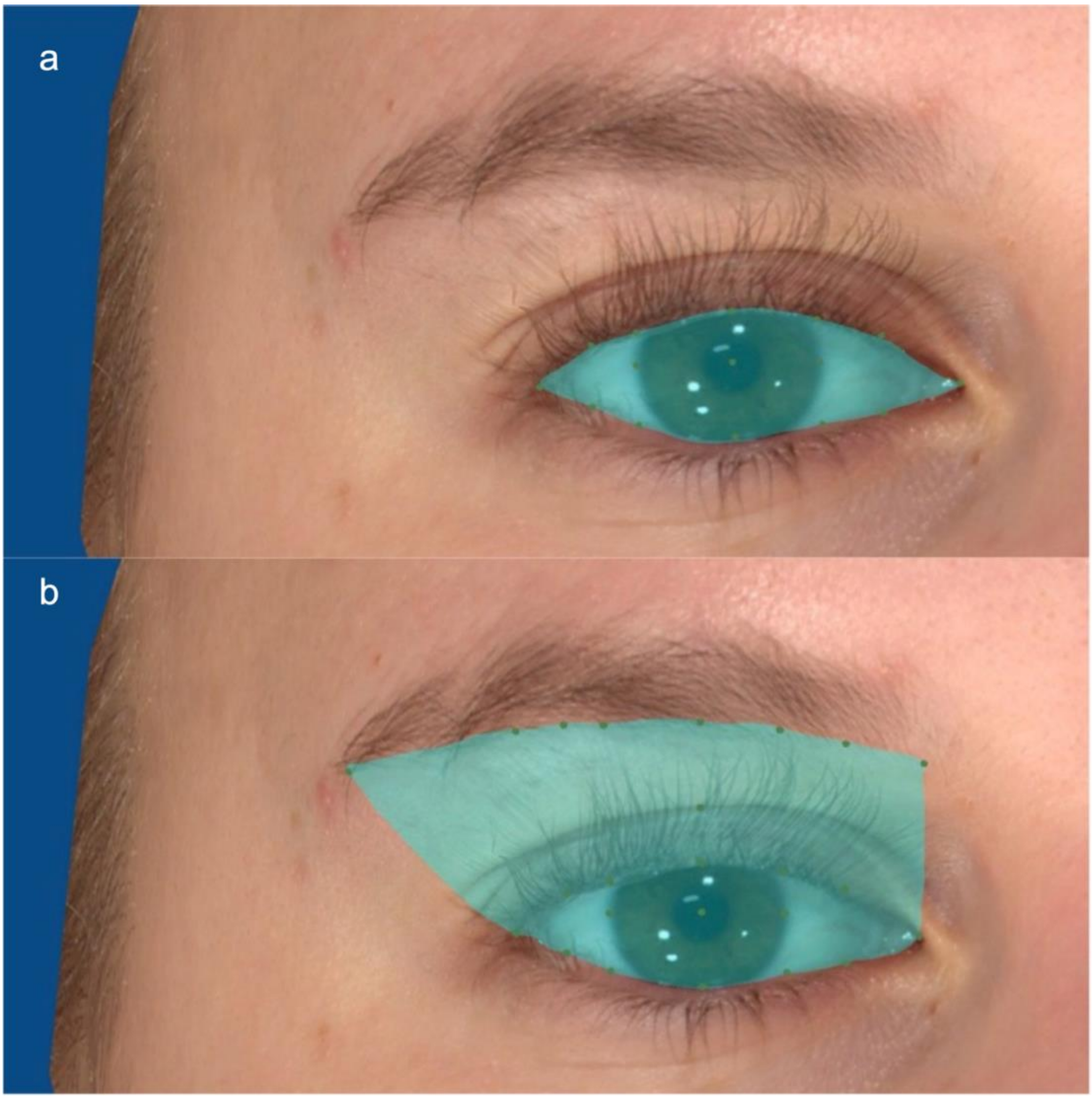

Figure 3. Periocular landmarks for measuring (a) the ocular surface area and (b) the whole periocular area

Table 2. Definition of linear distance for the periocular region

Abbreviation	Definition	Corresponding landmarks
Margin Reflex Distance 1 (MRD 1)	the distance from the pupil center to the vertically corresponding upper eyelid margin	Ps–Pc
Margin Reflex Distance 2 (MRD 2)	the distance from the pupil center to the vertically corresponding lower eyelid margin	Pc-Pi
Palpebral Fissure Height (PFH)	the distance between the upper and lower eyelid margins, which	Ps–Pi

	corresponds vertically to the pupil center	
Palpebral Fissure Width (PFW)	the horizontal distance between the medial and lateral canthi of the eye	Ex-En
Upper Eyelid Crease Distance (UEC)	vertically corresponding to the pupil center, corresponding to the distance from the upper eyelid point on the same side to the eyelid crease point	Ps–FPs
Pupil-to-Eyebrow Distance (PE)	the vertical distance from the pupil center to the lower edge of the eyebrow on the same side	Pc–EPs
Ocular Surface Area (OSA)	the uncovered area of the eyeball surrounded by the upper and lower eyelids	(En-Um-Lm’–Ps- Ll’- Ul- Ex-Ul’- Ll’’-Pi- Lm’’- Um’)
Whole Periocular Area (WPA)	the uncovered area surrounded by the lower eyelids and eyebrows	(EExl-EEx-EUl-ELl-Eps-Elm-EUm-EEn-En-Um’-Lm‘’-Pi-Ll‘’-Ul‘-Ex)

Modified from Guo Y et al.[69]

4.5 Statistical Analysis

Statistical analyses were carried out with IBM SPSS Statistics version 27 (IBM Corp., Armonk, NY, USA). The normal distribution is verified using the Shapiro–Wilk test. Demographic data are presented as medians and interquartile ranges. For paired samples, a paired t-test was applied when the data were normally distributed, whereas the Wilcoxon matched-pairs signed-rank test was used for data that did not follow a normal distribution. The Mann-Whitney U test was used to assess differences between independent groups for non-normally distributed variables. The relationship between average sleep duration and the asymmetry index was evaluated using Spearman correlation, with p-values below 0.05 considered statistically significant.

5. Results

5.1 Patient Demographics

A total of 110 Caucasian volunteers were involved in this study. They were divided into two groups: the SSP group had 52 participants (23 men and 29 women), while the Non-SSP group included 58 participants (26 men and 32 women). No significant difference in gender was found between the groups ($p = 0.950$). The average age also showed no significant difference between the two groups (48.5 ± 19.4 vs. 49.4 ± 19.0 years, $P = 0.749$). Daily sleeping duration was 7.7 ± 0.9 hours in the SSP group and 7.4 ± 1.0 hours in the Non-SSP group, with no significant difference ($P = 0.116$). (Table 3)

Table 3. Patient Demographics

	Sleeping side preference group	Non-preference Group	P-value
Age (years)	48.5±19.4	49.4±19.0	0.749
Male (%)	23(44.2)	26(44.8)	0.950
Daily Sleeping duration (hours)	7.7±0.9	7.4±1.0	0.116

5.2 Asymmetry Between Preferred and Non-Preferred Sleeping Sides

In the SSP group, MRD 1 was significantly smaller on the preferred side (5.072 ± 0.787 mm) than on the non-preferred sleeping side (5.915 ± 0.845 mm, $P < 0.001$). PFH was also reduced on the preferred side (10.192 ± 1.140 mm) compared to the non-preferred sleeping side (10.676 ± 1.186 mm, $P < 0.001$). In addition, the OSA was significantly smaller on the preferred sleeping side (2.307 ± 0.637 mm² vs. 2.383 ± 0.626 mm²), with this difference being statistically significant ($P = 0.045$).

There were no significant differences in MRD 2, PFW, UEC, PE, and WPA. The MRD 2 was identical on both sides, measuring 5.532 ± 0.760 mm on the preferred side and 5.532 ± 0.846

mm on the non-preferred side (p = 0.520). PFW also showed no meaningful difference, with values of 28.271 ± 2.533 mm and 28.554 ± 2.353 mm, respectively (p = 0.950). UEC was a little lower on the preferred side (3.441 ± 1.529 mm) than on the non-preferred side (3.664 ± 1.574 mm), but the difference was not significant (p = 0.107). PE also showed no significant difference between the two sides (16.573 ± 2.665 mm and 16.369 ± 2.849 mm; p = 0.413). WPA showed similar values, measuring 9.497 ± 1.504 mm^2 on the preferred side and 9.601 ± 1.492 mm^2 on the non-preferred side (p = 0.437). (Table 4) The distribution of these parameters between the preferred and non-preferred sleeping sides was shown in Figure 4. (Figure 4)

Table 4. Intragroup differences between the preferred and non-preferred sleeping sides in the sleeping side preference group

Parameters	Sleeping Side Preference Group		P-value
	Preferred sleeping side	Non-Preferred sleeping side	
MRD 1 (mm)	5.072±0.787	5.915±0.845	<0.001
MRD 2 (mm)	5.532±0.760	5.532±0.846	0.520
PFH (mm)	10.192±1.140	10.676±1.186	<0.001
PFW (mm)	28.271±2.533	28.554±2.353	0.950
UEC (mm)	3.441±1.529	3.664±1.574	0.107
PE (mm)	16.573±2.665	16.369±2.849	0.413
OSA (mm^2)	2.307±0.637	2.383±0.626	0.045

WPA (mm^2)	9.497±1.504	9.601±1.492	0.437

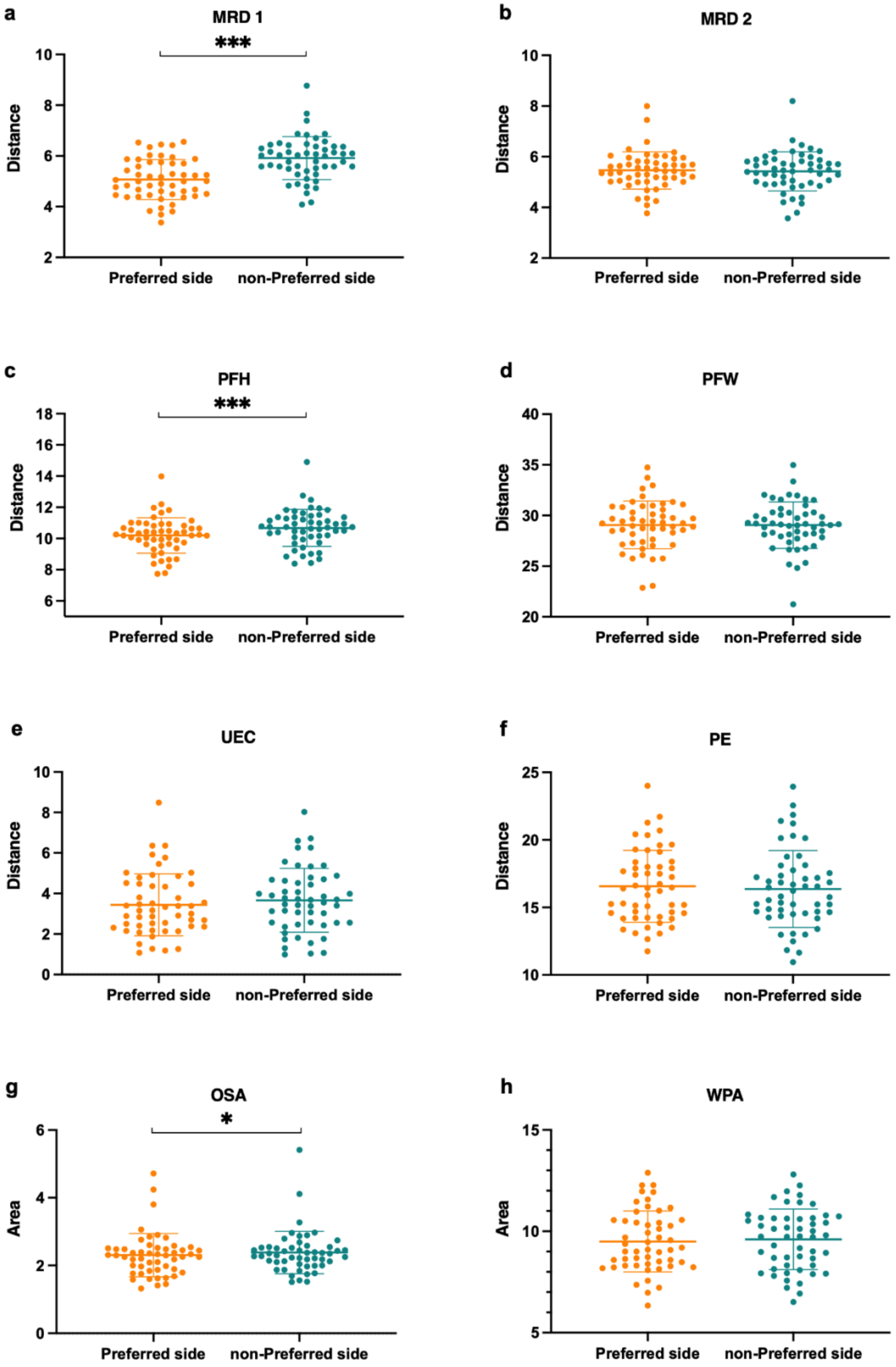

Figure 4. Parameter distribution between the preferred and non-preferred sides in the sleeping side preference group

a) The Margin Reflex Distance 1 (MRD 1); b) Margin Reflex Distance2 (MRD 2); c) Palpebral Fissure Height (PFH); d) Palpebral Fissure Width (PFW); e) Upper Eyelid Crease Distance (UEC); f) Pupil-to-Eyebrow Distance (PE); g) Ocular Surface Area (OSA); h) Whole Periocular Area (WPA). Significance levels: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

5.3 Asymmetry Index Between the SSP and Non-SSP Groups

Significant differences were observed in several periocular asymmetry indices between participants in the SSP and Non-SSP groups. The SSP group showed significantly higher asymmetry in MRD 1 compared to the Non-SSP group (17% [9.7%–24.6%] vs. 13.6% [8.7%–18.2%], $P < 0.001$). Similarly, the asymmetry in PFH (5.4% [2.0%–7.5%] vs. 2.6% [1.2%–5.4%], $P = 0.006$) and OSA (9.7% [5.6%–15.7%] vs. 7.5% [3.6%–10.0%], $P = 0.013$) was higher in the SSP group.

No significant differences were found between the two groups in MRD 2, PFW, UEC, PE, or WPA. The percentage difference in MRD 2 was nearly identical between the two groups, with the SSP group showing 4.6% (2.6%–7.6%) and the Non-SSP group 4.4% (2.2%–8.7%) ($p = 0.719$). A slight difference in PFW was observed, with a median of 1.7% (1.1%–2.8%) in the SSP group versus 2.2% (1.1%–5.2%) in the Non-SSP group, but this did not reach statistical significance ($p = 0.077$). The distribution of UEC values showed 20.3% (7.2%–45.6%) in the SSP group and 20.7% (10.5%–40.0%) in the Non-SSP group ($p = 0.658$). For PE distance, the SSP group had a slightly higher median difference of 9.0% (4.8%–11.9%) compared to 6.6% (3.5%–13.3%) in the Non-SSP group ($p = 0.165$). Lastly, differences in WPA were minor between groups, at 7.0% (3.8%–12.8%) and 8.8% (4.9%–12.8%) for SSP and Non-SSP, respectively ($p = 0.257$). (Table 5) The distribution of the asymmetry indices between the sleeping side preference group and the non-sleeping side preference group can be found in Figure 5.

Table 5. Comparison of Periocular Asymmetry Indices Between Sleeping Side Preference and Non-Sleeping Side Preference Groups

Parameters	Asymmetry Index		P-value
	Sleeping Side Preference Group	Non-Sleeping Side Preference Group	
MRD 1 (%)	17 (9.7-24.6)	13.6 (8.7-18.2)	<0.001
MRD 2 (%)	4.6 (2.6-7.6)	4.4 (2.2-8.7)	0.719
PFH (%)	5.4 (2.0-7.5)	2.6 (1.2-5.4)	0.006
PFW (%)	1.7 (1.1-2.8)	2.2 (1.1-5.2)	0.077
UEC (%)	20.3 (7.2-45.6)	20.7 (10.5-40.0)	0.658
PE (%)	9.0 (4.8-11.9)	6.6 (3.5-13.3)	0.165
OSA (%)	9.7 (5.6-15.7)	7.5 (3.6-10.0)	0.013
WPA (%)	7.0 (3.8-12.8)	8.8 (4.9-12.8)	0.257

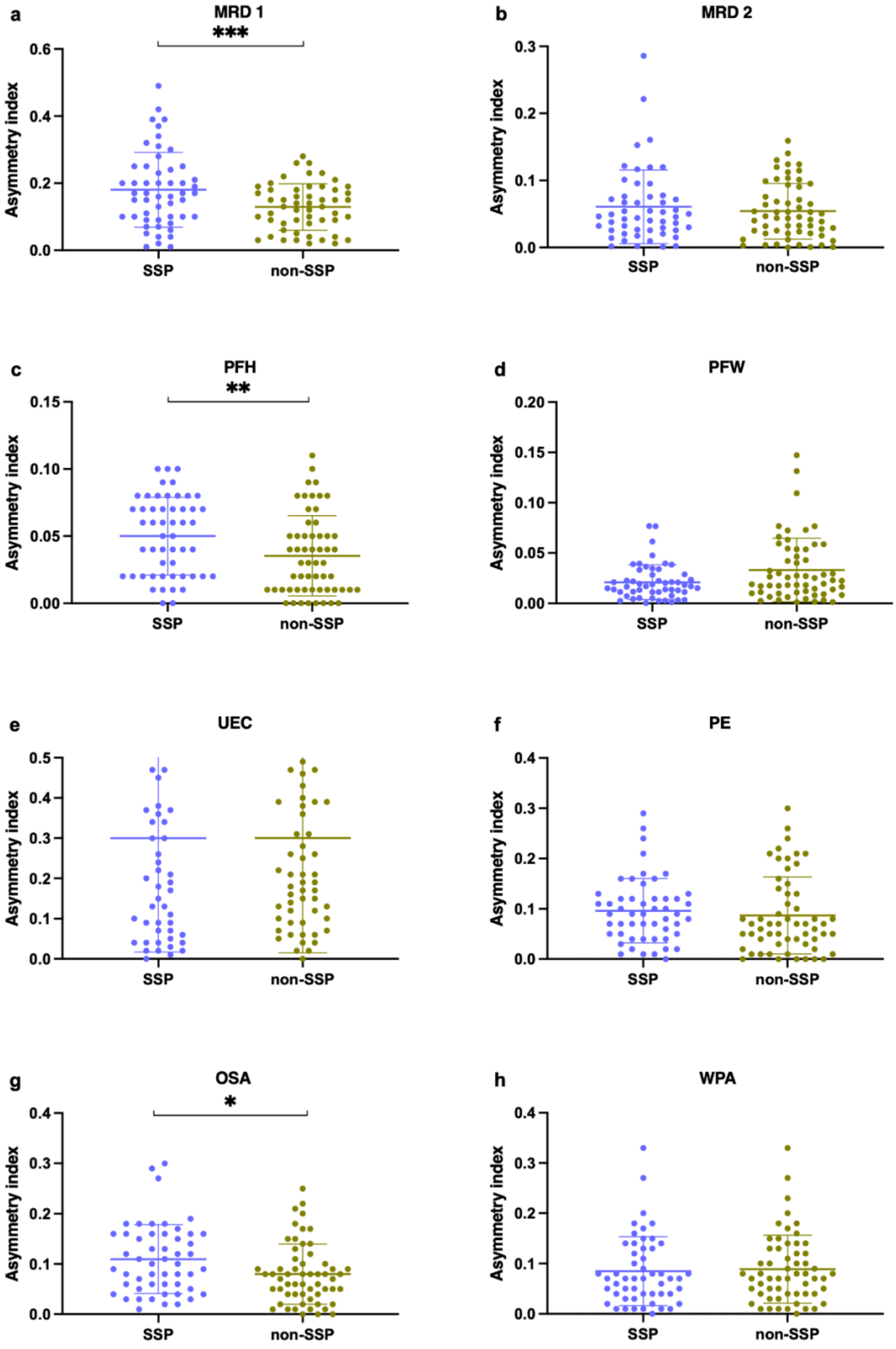

Figure 5. The distribution of the asymmetry indices between the sleeping side preference group and the non-sleeping side preference group

a) The Margin Reflex Distance 1 (MRD 1); b) Margin Reflex Distance 2 (MRD 2); c) Palpebral Fissure Height (PFH); d) Palpebral Fissure Width (PFW); e) Upper Eyelid Crease Distance (UEC); f) Pupil-to-Eyebrow Distance (PE); g) Ocular Surface Area (OSA); h) Whole Periocular Area (WPA). Significance levels: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

5.4 Relationship Between Sleep Duration and Periocular Asymmetry

No significant correlation was found in the SSP group between daily sleep duration and asymmetry indices across multiple measurements, including MRD 1 ($r = 0.056$, $P = 0.696$), MRD 2 ($r = -0.152$, $P = 0.281$), PFH ($r = 0.167$, $P = 0.237$), PFW ($r = -0.017$, $P = 0.908$), UEC ($r = -0.015$, $P = 0.914$), PE ($r = -0.169$, $P = 0.232$), OSA ($r = 0.093$, $P = 0.511$), and WPA ($r = 0.026$, $P = 0.857$). The association and distribution between asymmetry indices and sleeping duration in the sleeping side preference group were shown in Figure 6.

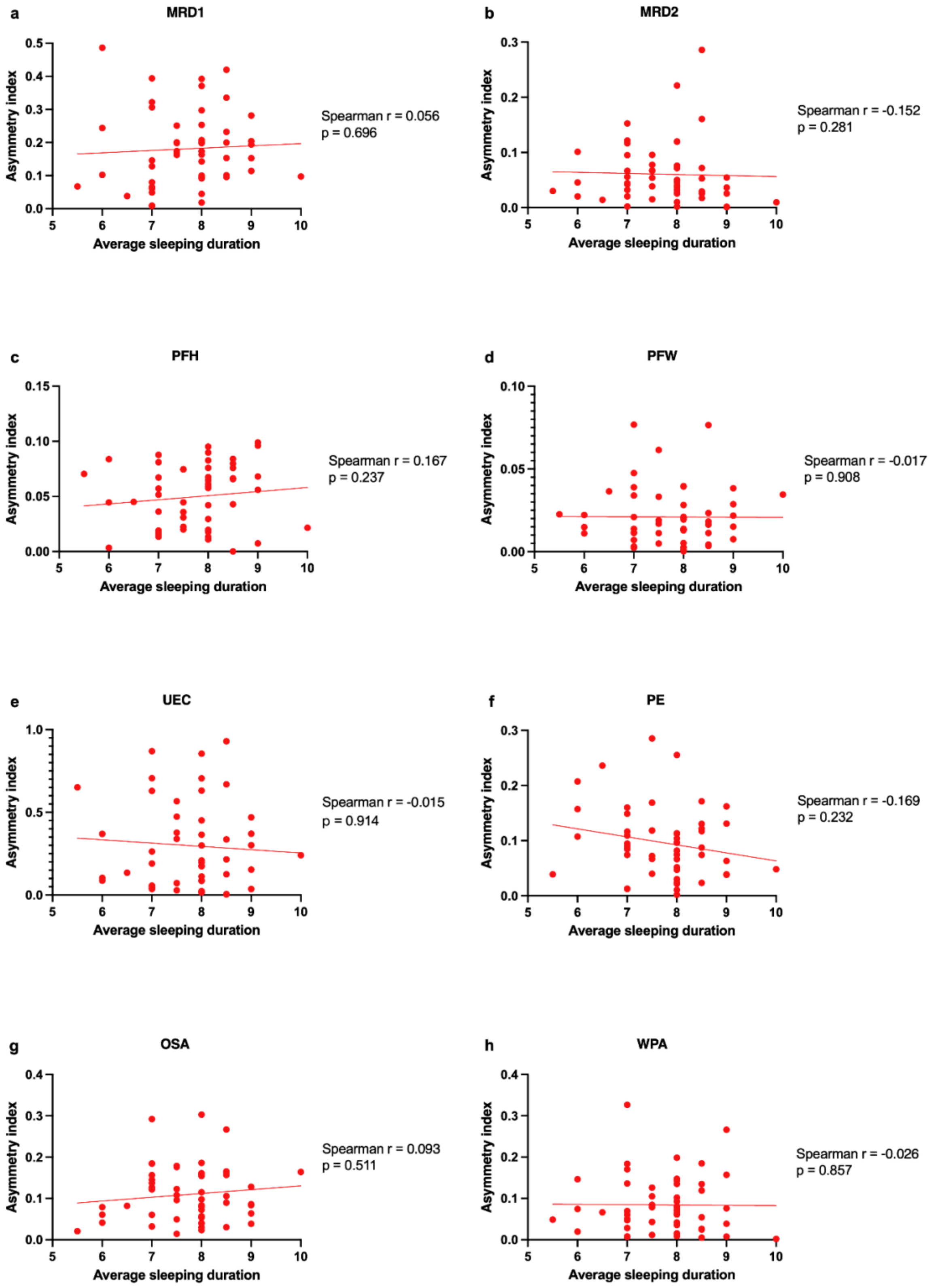

Figure 6. Pearson correlation between asymmetry indices and sleeping duration in the sleeping side preference group

a) Margin Reflex Distance 1(MRD 1) asymmetry index and daily sleeping duration; b) Margin Reflex Distance 2 (MRD 2) asymmetry index and daily sleeping duration; c) Palpebral Fissure

Height (PFH) asymmetry index and a daily sleeping duration; d) Palpebral Fissure Width (PFW) asymmetry index and daily sleeping duration; e) Upper Eyelid Crease Distance (UEC) asymmetry index and daily sleeping duration; f) Pupil-to-Eyebrow Distance (PE) asymmetry index and daily sleeping duration; g) Ocular Surface Area (OSA) asymmetry index and daily sleeping duration; h) Whole Periocular Area (WPA) asymmetry index and daily sleeping duration

6. Discussion

Previous studies demonstrated that 3D stereophotogrammetry was accurate and reliable in measuring facial imaging.[67,72] Although several studies have investigated eyelid-related diseases associated with sleep disorders, the influence of sleep posture on periocular asymmetry has yet to be fully investigated.[59,73,74] More specific studies are thus deemed essential in this area, mainly for the general population that can still exhibit minimal posture-related periocular changes. To the best of our knowledge, no previous study has quantitatively analyzed the impact of different sleeping postures on periocular asymmetry using 3D stereophotogrammetry. Compared to widely used 2D photographs, 3D photographs offer greater accuracy and reliability, allowing for a clearer assessment of periocular asymmetry.[28,62]

Our study found that the preferred sleeping side showed significantly lower MRD 1, PFH, and OSA compared to the non-preferred side in the SSP group. Corresponding asymmetry indices were also significantly greater in SSP than in Non-SSP participants. These results indicated that long-term side sleeping position could lead to asymmetry of PFH, MRD 1, and OSA. However, other periocular measurements, including MRD 2, PFW, UEC, PE, and WPA, did not show any significant differences. Furthermore, as patients' average sleep duration increased, no notable differences were detected.

Our results suggested that sleeping position may lead to asymmetry in periocular structures, mainly manifested as decreased upper eyelid height. These observations of periocular feature measurements at preferred sides of sleep were consistent with those of previous studies that analyzed preferred sides of sleep.[16,19,58,73-75] There was no correlation between increased sleep duration and the degree of asymmetry. There may be a threshold effect, as most patients had indicated sleep duration within a narrow range (6.5–8.5 hours).[74] If more patients who lie on their side for longer periods are measured, new findings might emerge.

Our study found statistically significant differences in the asymmetry index of PFH, MRD1, and OSA between the two groups. Furthermore, within the SSP group, the preferred sleeping side showed decreased PFH, MRD1, and OSA. This could be explained by a change in the position of the upper eyelid. Prior studies have reported that side-dominant sleepers show increased laxity of the eyelids[19,20,76], and some researchers have proposed similar observations linking side sleeping to soft tissue changes.[59,60]

It is plausible to speculate that gravity and sustained mechanical pressure from habitual side sleeping may promote periocular tissue relaxation, thereby affecting the position of the eyelid. A plausible mechanism has been proposed by other researchers: repetitive mechanical compression on one side of the face during sleep may act as external tissue molding.[77] Under cyclical pressure, soft tissues may undergo subtle yet cumulative displacement and deformation. This process could be explained by creep, a phenomenon in which biological tissues experience gradual deformation under prolonged load, or by repetitive stress cycles over time.[73,78] Eventually, these changes may lead to mild but visible periocular asymmetry, particularly around dynamic anatomical regions such as the upper eyelids.

While causality cannot be confirmed, our findings can support the hypothesis that long-term unilateral mechanical loading during sleep may contribute to subtle structural differences between the two sides of the upper eyelid. Notably, our results did not show a significant effect of sleeping side preference on lower eyelid position.

Notably, there were no statistically significant differences in PE and the WPA asymmetry index between the two groups. To further understand the lack of asymmetry in other periocular parameters, such as PE and WPA, it is important to consider the role of neuromuscular control in eyelid and eye coordination. The oculomotor nerve innervates the superior rectus, medial rectus, and levator palpebrae superioris muscles, resulting in coordinated eyelid and eye movements.[79-82] This may be explained by gravitational effects on the dependent eye in the side-sleeping position, leading to a relative predominance of the lateral rectus muscle. Simultaneously, reduced engagement of the oculomotor nerve and its innervated muscles may result in a decrease in PFH and consequently a reduction in OSA on that side.

In addition, when the upper eyelid is relaxed and the upper visual field is limited, the body raises the eyebrows through compensatory contraction of the frontalis muscle to lift the upper eyelid and restore the visual field.[83-86] Such compensation is typically bilateral and symmetrical, which could explain the absence of significant asymmetry in PE and WPA, despite unilateral upper eyelid reduction.

Although eyebrow lifting can compensate for the effect of upper eyelid laxity on the visual field to some extent, this compensation cannot completely offset the effect of decreased PFH on the ocular surface, which may explain the significant reduction in OSA on the side of side sleep preference.[85] It is reasonable to speculate that the coordinated movement of the eyelid and eyeball can partially buffer the decrease in PFH, but it still cannot completely prevent the occurrence of functional asymmetry of OSA.

Existing literature concerning sleep posture and its link to periocular asymmetry has been primarily based on 2D image analysis, which limits the systematic study of the periocular region.[74] 2D methods generally require a high degree of subject cooperation and are susceptible to measurement errors, particularly due to the delicate structural details of the periocular region. 3D stereophotography is less labor-intensive and less dependent on subject cooperation compared to classical direct anthropometry, as it reduces sources of error from subject displacement or posture.[87] Notably, 3D stereophotography permits precise quantification of facial surface area measures such as OSA and WPA, which are crucial in detecting subtle facial soft tissue asymmetries. The greater precision and full data acquisition potential provided by 3D stereophotography constitute an ideal technique, thereby augmenting the reliability and clinical relevance of our findings.[28]

However, our research has several limitations. Firstly, no consideration was given to intervening factors, such as pillow and mattress material used by participants, that might influence the outcome as well.[88,89] Secondly, data on average sleep duration relied on selfreports, which may be affected by subjectivity. In order to add objectivity to measurements of sleep duration, future research needs to consider including monitoring devices, such as smart wristbands or other wearable technology, to record more accurate and uniform data regarding sleep. Thirdly, our study focused solely on periocular asymmetry. Future research should broaden its scope to include asymmetries in other facial regions, such as the cheeks.

The study revealed that maintaining a one-sided sleeping position is correlated with higher upper eyelid asymmetry. This information may be helpful for raising public awareness about the effects of long-term lateral sleeping and for encouraging preventive measures. For individuals with pre-existing periocular asymmetry, recommending changes in sleep posture may be an evidence-based strategy to slow further progression. Clinically, these results could offer valuable reference for both preoperative and postoperative consultations, supporting more personalized treatment plans based on patients' sleep habits.[1,90] Therefore, incorporating sleep posture evaluation into clinical consultations may represent a simple yet effective strategy for managing periocular asymmetry.

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8. Appendix

8.1 List of Figures

8.2 List of Tables

9. Vorabveröffentlichungen von Ergebnissen