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New keratoconus staging system based on OCT

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Purpose: To establish a numerical spectral-domain optical coherence tomography (SD-OCT)-based keratoconus (KC) staging system and compare it with existing KC staging systems.

Setting: Eye Hospital of Wenzhou Medical University, Wenzhou, China.

Designs: Retrospective case-control study.

Methods: Scheimpflug tomography, air-puff tonometry, and SD-OCT were performed on 236 normal and 331 KC eyes. All SD-OCT-derived parameters of the corneal epithelium and stroma were evaluated based on their receiver operating characteristic (ROC) curves, area under the curve (AUC), sensitivity, and specificity to discriminate between normal and KC eyes. The best performing parameters were subsequently used to create an OCT-based staging system, which was compared with existing tomographic and biomechanical staging systems.

Results: 236 eyes from 236 normal patients and 331 eyes from 331 KC patients of different stages were included. The highest ranked AUC ROC SD-OCT parameters, derived from stroma and epithelium, were stroma overall minimum thickness (ST: AUC 0.836, sensitivity 90%, specificity 67%) and epithelium overall SD (EP: AUC 0.835, sensitivity 75%, specificity 78%). A numerical SD-OCT staging system called STEP including 2 parameters—"ST" and "EP"—with 5 stages was proposed.

Conclusions: The new SD-OCT-based KC staging system is the first to take the epithelium with its sublayer stroma information into account, showing a strong agreement to the existing staging systems. This system could be incorporated into daily practice, potentially leading to an overall improvement in KC treatment and follow-up management.

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Keratoconus (KC) is a bilateral corneal ectatic disorder characterized by local biomechanical weakness, corneal thinning, and protrusion.[1] This can result in increasing myopia, irregular astigmatism, corneal scarring, and loss of vision.[2] Existing studies indicate that early diagnosis with timely corneal crosslinking (CXL) can slow or halt KC progression and that early diagnosis can also prevent inappropriate refractive laser treatment in cases of subclinical disease.[3]

Placido topography is typically used to assess the corneal curvature for signs of KC while Scheimpflug tomography added corneal elevation and more complex parameters for KC diagnosis and staging. By training new algorithms and adding automation to the analysis, our ability to diagnose KC early, accurately, and efficiently could be significantly improved.[4] In the past, maximum keratometry (K_{max}) was regarded as a simple and useful index to assess KC severity,

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and many still use it to monitor progression.[5] However, K_{max} is a single-point measurement, which has a low repeatability in advanced KC cases.[6,7] The Belin ABCD staging system was introduced to provide a more robust KC progression and staging method.[5] These tomographic techniques, however, omit a key feature of KC, namely change in corneal biomechanics. Combining an air-puff tonometer with high-speed Scheimpflug imaging (Corvis, Oculus Optikgeräte GmbH) captures this aspect, and by analyzing dynamic corneal response parameters, the Corvis Biomechanical Index (CBI) has been proposed as a means of augmenting early KC diagnosis.[8,9] The linear form of the CBI has recently been used to generate an Elastic staging system that was later combined with the Belin ABCD staging system.[10–12]

Compared with the Scheimpflug technology, anterior segment optical coherence tomography (AS-OCT) provides yet greater image resolution. AS-OCT can differentiate the corneal epithelium and other corneal layers with a resolution that the Scheimpflug technology cannot deliver.[13] The corneal epithelial profile had been proven to benefit early-stage KC detection, although it was first described and measured using very high-frequency digital ultrasound, which is not routinely used clinically.[14–18]

Ideally, a disease staging system should have some key features, including (1) the ability to diagnose early to assist in the follow-up of patients in a timely manner, (2) objective numeric parameters that change linearly as the disease progresses to assess the disease severity, (3) as few parameters as possible to evaluate the disease in multiple dimensions and to facilitate clinical application, and (4) being platform-independent and not limited to a specific device or algorithm.[19,20] However, to date, the corneal epithelium and its underlying stromal layer have not been considered in a data-driven KC staging system.

The aim of this study was to use AS-OCT to create a KC staging system that includes the epithelium with its stromal sublayer information, based on a large population of both normal patients and patients with KC, with an emphasis on integration into clinical practice. We also aimed to compare it with existing tomographic and biomechanical KC staging systems to evaluate its performance relative to the current standard.

METHODS

This retrospective study was conducted with the approval of the ethics committee of the Eye Hospital of Wenzhou Medical University.

Patients Inclusion and Database

This study included 2 groups of patients—the normal/control group and KC group. Before examination, patients were asked to discontinue soft contact lens wear for at least 2 weeks or at least 4 weeks for rigid gas-permeable contact lenses. All measurements were obtained in a consistently dimly lit examination room by experienced technicians before the instillation of fluorescein.

The normal patient group was recruited from those seeking laser vision correction in the Eye Hospital of Wenzhou Medical University. The inclusion criteria comprised the absence of ocular or systemic abnormalities and a negative of ocular surgery, a stable corrected distance visual acuity (CDVA) ≥20/20 for 2 years preoperatively with Scheimpflug tomography (Pentacam HR, Oculus Optikgeräte GmbH), and confirmed by 4 cornea specialists. To avoid the inclusion of forme fruste KC in the normal group, a minimum of 3 years of follow-up was required after laser vision correction to exclude possible iatrogenic ectasia. For the normal group, only 1 randomly selected eye was included per person.

In the KC group, the diagnosis of KC was also confirmed by 4 cornea specialists. The diagnosis typically required 2 typical signs of KC on Scheimpflug tomography, such as abnormal corneal thickness distribution and thinnest pachymetry, abnormal posterior elevation, skewed asymmetric bowtie/inferior steepening (SAB/IS) or increased inferior steepness, and/or one classic slitlamp finding (Fleischer ring, Vogt striae, or central thinning).

After the confirmation of the KC diagnosis, for each patient with KC, only the eye with the mildest KC manifestation was selected and included. As a result of selecting the less affected side, these cases included some KC eyes that did not manifest any slitlamp findings. They were further categorized into 3 subgroups: the forme fruste KC (FFKC), early-stage KC (EKC), and advanced KC (AKC) subgroups.[21] The inclusion criteria of the FFKC subgroup were best CDVA ≥20/20, no KC signs at slitlamp, K_{max} <47.4 diopters (D), thinnest pachymetry ≥480 μm, normal tomography with the difference between K_{max} values in the inferior and superior areas at 3 mm (IS-Value) of <1.4 D, and no SAB/IS.[4,22,23] For the EKC subgroup, the criteria were K_{max} <48.5 D, smallest thickness >480 μm, best CDVA ≥16/20, no central scars, and fewer than 2 slitlamp findings. The criteria for the AKC subgroup were KC eyes with parameters exceeding those of the FFKC and EKC subgroups.

Scheimpflug Tomography

Tomography measurements were obtained using Pentacam HR software (v. 1.25r12). Only eyes with OK quality measurements were included. The following parameters were recorded: K_1; K_2; K_{max}; corneal thinnest pachymetry; IS-Value; and the values of A, B, and C read from the Belin ABCD staging, where A and B stand for the anterior and posterior radius of curvature for a 3.0-mm zone centered on the thinnest point, respectively, and C stands for the thinnest pachymetry while D refers to CDVA, a subjective parameter that was not included in the current analysis. The Scheimpflug tomography was only used to set up the new OCT-based system, but is not included in the new OCT-based system itself.

Corneal Biomechanics Using High-Speed Dynamic Scheimpflug Imaging

The corneal biomechanical properties were measured by Corvis (software v. 1.6r2503), and only measurements with an acceptable quality were included for analysis. The data recorded included the Stress–Strain Index, CBI, Tomographic and Biomechanical Index, Corvis Biomechanical Factor, and Elastic stage.[9,11,12,23,24]

Spectral-Domain OCT

AS-OCT measurements were performed with the RTVue-XR Spectral-Domain OCT (SD-OCT, Optovue, Inc.) in a pachymetry-wide scan pattern, which is known to provide an excellent repeatability.[25] For each eye, 3 continuous scans were conducted. The whole corneal, epithelium, and stromal thickness maps were recorded in the central (2 mm diameter), paracentral (2 to 5 mm), midperipheral (5 to 7 mm), and peripheral (7 to 9 mm) regions. In the latter 3 regions, the thickness was monitored in 8 equally spaced points along the median circumference of the area, including the temporal (T), superior-temporal (ST), superior (S), superior-nasal (SN), nasal (N), inferior-nasal (IN), inferior (I), and inferior-temporal (IT) positions.

All parameters were derived from the measured thickness of the 3 different corneal layers by the OCT software (ReVue v. 2018.0.04, Optovue, Inc.). These measurements included (1) Pachymetric/Epithelial/Stromal Minimum Thickness: the

minimum thickness in the whole corneal/epithelial/stromal layer; (2) Pachymetric/Epithelial/Stromal Min-Max: the minimum thickness in the whole cornea/epithelium/stroma minus the maximum thickness in the whole cornea/epithelium/stroma; (3) Pachymetric/Epithelial/Stromal 5-mm/7-mm SN-IT/ST-IN/S-I: the average thickness of the whole cornea/epithelium/stroma in the SN/ST/S area, respectively, minus that of the whole cornea/epithelium/stroma in the IT/IN/I area, respectively, between the paracentral/midperipheral regions; and (4) Pachymetric/Epithelial/Stromal Overall SD: the SD of the whole corneal/epithelial/stromal thickness.

SD-OCT–Based Staging System Building

The software R (v. 4.2.0, R Foundation for Statistical Computing; https://www.R-project.org/) was used to perform feature selection on the OCT parameters using the *Boruta* package (v. 7.0.0).[26] Next, receiver-operating characteristic (ROC) curve analyses were performed to identify those parameters that discriminate best between normal and KC eyes. The 5 best performing stromal and epithelial parameters with the highest area under the curve (AUC) values, along with their cutoff values, were then recorded.

To build the staging system, the highest ranked AUC ROC SD-OCT parameter of stroma (ST) and epithelium (EP) was selected to form the new STEP staging system. All cases with ST and EP values above or below the AUC cutoffs were defined as stage 0 (normal) while cases with stage >0 were considered as KC. The lower and upper limits to the scale for ST and EP parameters were set at the lower and upper boundaries of the 95% range (ie, mean ± 1.96 ×1 the SD), respectively, to avoid including outliers. The remaining range from the AUC cutoffs to the lower or upper limit to the scale was then divided into 4 quartiles in accordance with the existing tomographic and biomechanical systems, thus forming the cutoff values of each stage. Finally, to optimize and finalize the staging system for translation to the clinic, discussions were held among experts (consisting of 10 international members, including corneal specialists, each with more than 15 years of experience in KC diagnosis and management) in virtual meetings and through multiple emails. The discussions pertained to the adjustment and determination of cutoff values in each stage of 2 parameters—the confirmation and explanation of practical clinical utility of the current new OCT-based staging methods proposed here.

Staging System Distributions and Comparisons

The distribution of each parameter from the current new staging system was assessed. Based on cross-tabulation, the distribution of the staging system was compared with that the tomographic Belin ABC and biomechanical Corvis elastic staging systems.

Statistical Analysis

Statistical analysis was performed in SPSS (v. 24; IBM Corp.) and R. The normality of the data was verified using the Shapiro-Wilk test. Descriptive statistics were presented as mean ± SD. For continuous variables, *t* test and Mann-Whitney *U* test were used to analyze the differences between the groups. A value of *P* less than 0.05 was considered statistically significant for all tests. To determine the optimal cutoff values, sensitivity, and specificity, ROC curves and AUC were applied as accuracy measures. Whereas an AUC value of 1.0 indicates perfect discrimination, values ≤0.5 show that the assessed parameter has no diagnostic ability. Values between 0.5 and 1.0 refer to a significant difference between the distributions of the considered variables in 2 groups.

RESULTS

Demographics

This retrospective study included 567 eyes of 567 patients, for whom the basic demographic information is provided in Table 1. The distribution of the parameter values and comparisons between the normal and KC groups are shown in Figure 1. For the KC group, there were a total of 331 eyes of 331 patients with KC, including 50 FFKC eyes of 50 patients, 56 EKC eyes of 56 patients, and 225 AKC eyes of 225 patients. There were no significant differences in age between the 2 groups (P = .832).

The Top AUC Parameters and Staging System

Comparing between the normal and KC groups, the greatest 5 AUC stromal and epithelial corneal parameters are summarized in Table 2 (all P values < 0.001). For the stromal parameters, the top AUC ROC ranked parameter was Stroma Overall Minimum Thickness (cutoff value = 436.89, AUC = 0.836). For the epithelial parameters, the top AUC ROC ranked parameter was Epithelium Overall SD (cutoff value = 2.34, AUC = 0.835). The cutoff values of the stages were discussed and modified by the experts, leading to the staging system presented in Table 3.

Table 1. Basic demographics

Parameter	Normal	Keratoconus	*P* value
Original database to build the system			
n (R/L)	117/119	171/160	—
Sex (M/F)	106/130	239/92	—
Age (y)	22.12 ± 6.22	22.18 ± 6.40	.832
K_1 (D)	42.45 ± 1.52	44.19 ± 3.16	<.001
K_2 (D)	43.68 ± 1.63	47.05 ± 4.02	<.001
K_{max} (D)	44.36 ± 1.49	51.56 ± 7.12	<.001
IS-Value (D)	0.20 ± 0.66	3.29 ± 3.11	<.001
Pachy min (μm)	538.83 ± 30.48	484.82 ± 40.95	<.001
BADD	1.18 ± 0.64	5.76 ± 3.85	<.001
PRFI	0.13 ± 0.11	0.78 ± 0.31	<.001
SSI	0.87 ± 0.12	0.80 ± 0.16	<.001
CBI	0.23 ± 0.27	0.77 ± 0.34	<.001
CBiF	6.25 ± 0.37	5.14 ± 0.81	<.001
TBI	0.26 ± 0.19	0.87 ± 0.27	<.001
Validation database			
n (R/L)	26/21	37/34	—
Sex (M/F)	30/17	53/18	—
Age (y)	21.87 ± 3.83	21.13 ± 7.37	.525
K_1 (D)	42.07 ± 1.18	44.51 ± 4.55	<.001
K_2 (D)	43.50 ± 1.29	47.37 ± 5.44	<.001
K_{max} (D)	44.11 ± 1.31	51.55 ± 8.55	<.001
IS-Value (D)	0.11 ± 0.58	3.07 ± 3.21	<.001
Pachy min (μm)	548.60 ± 29.42	487.85 ± 52.00	<.001
BADD	0.92 ± 0.52	5.61 ± 5.25	<.001
PRFI	0.08 ± 0.08	0.69 ± 0.37	<.001
SSI	0.90 ± 0.13	0.83 ± 0.16	.014
CBI	0.30 ± 0.21	0.78 ± 0.28	<.001
CBiF	6.41 ± 0.35	5.30 ± 1.03	<.001
TBI	0.13 ± 0.13	0.79 ± 0.33	<.001

BADD = Belin-Ambrósio Deviation Index; CBI = Corvis Biomechanical Index; CBiF = Corvis Biomechanical Factor; IS-Value = difference between mean inferior and superior corneal powers 3 mm from the center of the cornea; Pachy min = corneal thinnest pachymetry measured by Scheimpflug tomography; PRFI = Pentacam Random Forest Index; SSI = Stress–Strain Index; TBI = Tomographic and Biomechanical Index

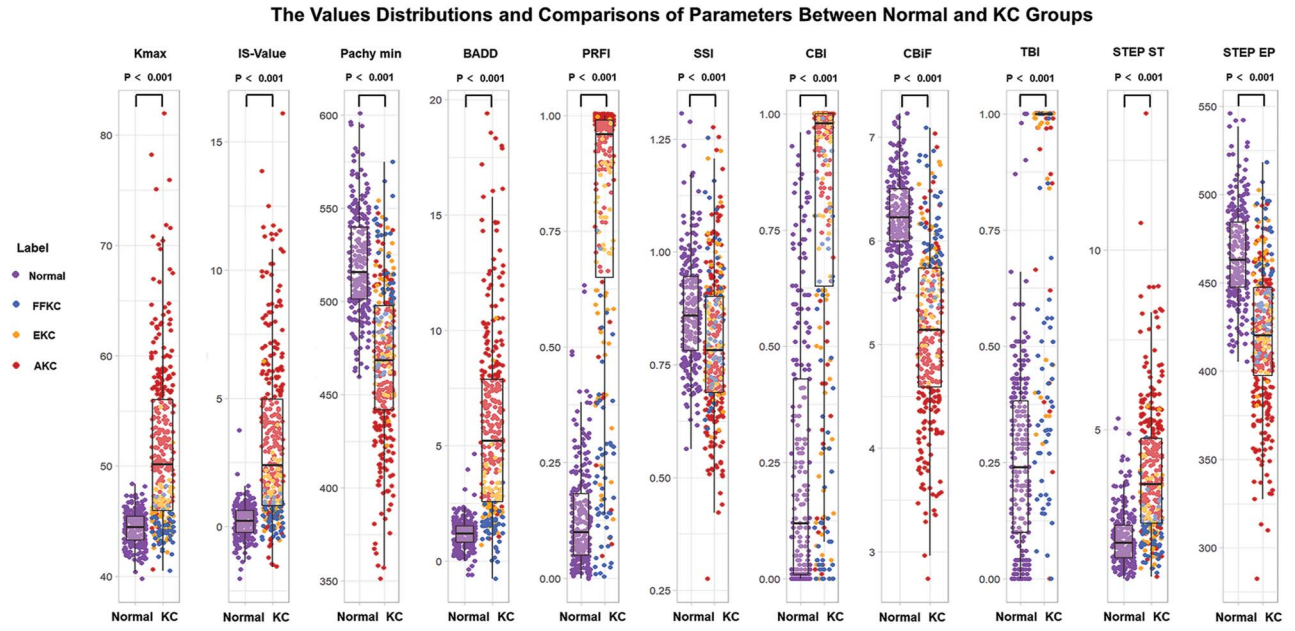

Figure 1. Value distribution and comparison of parameters between the normal and KC groups. AKC = advanced KC; BADD = Belin-Ambrósio Deviation Index; CBI = Corvis Biomechanical Index; CBiF = Corvis Biomechanical Factor; EKC = early-stage KC; FFKC = forme fruste KC; IS-Value = difference between mean inferior and superior corneal powers 3 mm from the center of the cornea; KC = keratoconus; Pachy min = corneal thinnest pachymetry measured by Scheimpflug tomography; PRFI = Pentacam Random Forest Index; SSI = Stress–Strain Index; STEP EP = Epithelium Overall SD; STEP ST = Stroma Overall Minimum Thickness; TBI = Tomographic and Biomechanical Index

Distributions and Comparisons

The detailed cross-tabulation of staging distributions between the STEP and Belin ABC staging systems and between the STEP and Corvis Elastic staging systems in the normal and KC groups are shown in Figure 2, *a* and *b*, respectively. Below the figures, the corresponding relative frequencies of the STEP system compared with Belin ABC and Corvis Elastic staging systems were also calculated and compared to summarize the consistency of staging distributions. Two representative cases of KC in different stages are presented in Figure 3 and Supplemental Figure I (available at http://links.lww.com/JRS/A964).

Owing to similar origins, the STEP ST parameter could only be compared with value C from the Belin ABC staging system, showing a good agreement for both normal and KC groups (90.68% normal eyes and 75.53% KC eyes were located at the same stage). Meanwhile, the STEP EP parameter was compared with values A and B from the Belin ABC staging system and Corvis Elastic system. In the normal group, 74.58% eyes were of the same stage for STEP parameter EP and Belin value A, 73.31% for STEP parameter EP and Belin value B, and 60.59% for STEP parameter EP and Corvis Elastic stage. In the KC group, the agreement was relatively high, ranging between 35% and 41%, while inconsistencies of ≥2 stages between STEP parameter EP and Belin value B and between STEP parameter EP and Corvis Elastic stage (eg, eyes of stage 3 in STEP parameter EP and stages 0 and 1 in Corvis Elastic) were both limited to 15%.

Independent Validation

For the validation of the STEP system, a total of 47 normal eyes from 47 healthy patients and 71 eyes from 71 patients with different stages of KC (including 27 FFKC, 10 EKC, and 34 AKC) were included. The demographic information and comparison between the 2 groups are presented in Table 1. The cross-tabulation of staging distributions between the staging systems in 2 groups are shown in Supplemental Figure II (available at http://links.lww.com/JRS/A964). In the normal group, the STEP system agreed very well with the Belin ABC and Corvis Elastic staging systems; more than 85% of patients were in the same stage in all the comparisons. In the KC group, the staging agreement was still relatively high (ranging between 47% and 77%).

DISCUSSION

This study describes the establishment of a comprehensive numeric SD-OCT–based KC staging system. This OCT-based KC staging system is named STEP as it is based on 2 parameters—Stromal Overall Minimum Thickness (ST) and Epithelium Overall SD (EP).

STEP is the first approach to incorporate both corneal epithelial and stromal information into a KC staging system. One practical application of the STEP ST parameter could be to facilitate the decision process of CXL protocols. For example, in advanced KC cases, the classic Dresden protocol is often not appropriate if the stromal pachymetry is below 400 μm (STEP ST >stage I). In such cases, the sub400 or other alternative CXL protocols might be

Table 2. Top 5 AUC SD-OCT–based parameters from stromal and epithelial layers

Feature	Normal	Keratoconus	AUC	95% CI	Cutoff value	Sensitivity	Specificity
a: The top 5 AUC stroma parameters							
Stroma overall min thickness	466.20 ± 26.93	419.88 ± 38.76	0.836	0.804, 0.868	436.89	0.903	0.671
Stroma 5-mm IT thickness	483.87 ± 28.12	445.92 ± 33.43	0.809	0.774, 0.844	458.36	0.847	0.665
Stroma min-med thickness	−48.32 ± 6.09	−65.08 ± 20.81	0.798	0.762, 0.834	−58.48	0.970	0.547
Stroma 2-mm thickness	473.13 ± 27.10	436.17 ± 35.37	0.793	0.757, 0.829	444.46	0.886	0.607
Stroma 9-mm S thickness	621.76 ± 36.46	584.61 ± 41.24	0.756	0.717, 0.795	598.17	0.754	0.671
b: The top 5 AUC epithelium parameters							
Epithelium overall SD	1.99 ± 0.77	3.76 ± 1.80	0.835	0.803, 0.868	2.34	0.750	0.779
Epithelium 5-mm SN-IT thickness	−0.79 ± 1.87	4.33 ± 5.42	0.826	0.793, 0.860	1.37	0.911	0.674
Epithelium overall min-max thickness	−9.86 ± 3.63	−17.35 ± 7.92	0.813	0.778, 0.847	−13.89	0.898	0.616
Epithelium 5-mm IT thickness	54.41 ± 3.46	50.21 ± 4.73	0.778	0.740, 0.816	51.83	0.809	0.668
Epithelium 5-mm S-I thickness	−1.91 ± 2.22	1.68 ± 4.86	0.747	0.707, 0.787	1.25	0.936	0.514

AUC = area under the curve; I = inferior; IT = inferior-temporal; Max = maximum; Med = median; Min = minimum; N = nasal; S = superior; SN = superior-nasal; T = temporal

indicated.[27] For the STEP EP parameter, when the epithelium becomes more asymmetric to smoothen the irregular stromal surface during KC progression, STEP parameter EP, which reflects remodeling, increases correspondingly. It also indicates the degree of epithelial redistribution. Furthermore, it could potentially act as a tool for evaluating CXL effectiveness evaluation and follow-up, as the difference in epithelium thickness distribution was shown to become less in post-CXL stable post-ectasia and KC patients.[28,29]

Our outcomes aligned well with previous studies using an alternative SD-OCT device (MS-39, Costruzione Strumenti Oftalmici), where the authors demonstrated a good correlation between the degree of visual limitation (and KC severity staging) and stromal and epithelial thickness parameters.[30] In these studies, the superior–inferior ratio at 6 mm and 8 mm played a major role, reflecting the performance of the STEP parameter EP for the irregular distribution of epithelial thickness throughout the cornea, although an OCT-based KC staging system was not developed in their studies.

In reviewing the existing KC staging systems, the first KC staging system was proposed by Amsler, which was later updated to the Amsler-Krumeich (AK) staging system by Krumeich et al.[31,32] Alió and Shabayek later introduced the corneal coma-like aberrations to the AK staging system while Ishii et al. integrated 6 front-surface parameters into the AK staging system.[33,34] Belin et al. established the Belin ABCD system by expanding the AK staging system to include 5 stages, adding the posterior surface curvature, switching from the corneal central thickness to the corneal thinnest thickness, and modifying the values of all objective parameters in the mildest stage based on the results of ROC analyses.[35] Sandali et al. first established an OCT-based structural staging system by describing the corneal structural remodeling through the sectional scan observation.[36] However, the descriptions are not numerical, which makes it prone to potential discrepancies in clinical practice. While the STEP system overcomes this limitation, the structural staging system modified by Sandali still could be used to augment the STEP system by providing visualized structural information. Furthermore, ocular surface disorders such as severe dry eye, epithelial basement membrane dystrophy, and contact lens-induced epithelial remodeling warpage can affect the epithelial profile measurement, thus reducing the accuracy of the STEP system.[37] The system should, therefore, be combined with a clinical slitlamp examination to distinguish such ocular surface disorders from KC. Caution is especially warranted in applying the STEP system to cases where patients with KC simultaneously suffer for these ocular surface disorders.[38] Recently, Yousefi et al. first built a numeric OCT-based staging system by principal component analysis.[39] Though interesting, such a system does not explicitly present stromal and epithelial information, making clinical interpretation difficult. The 2 machine-derived parameters of the STEP system, on the other hand, are far easier to interpret.

Table 3. SD-OCT–based staging system: STEP

Criteria	Stage 0	Stage I	Stage II	Stage III	Stage IV
ST (μm)	≥435	>400	>350	>300	≤300
EP (μm)	≤2.30	<3.00	<4.00	<5.00	≥5.00

ST = Stroma Overall Minimum Thickness; EP = Epithelium Overall SD

For the agreement between the STEP system and the Belin ABCD staging system, the validation study showed a similar result with the original dataset, which is currently used for the STEP system establishment: When compared with the Belin ABCD staging system, the STEP ST parameter agreed well with Belin value C because of the similar description, but the STEP parameter EP agreed less

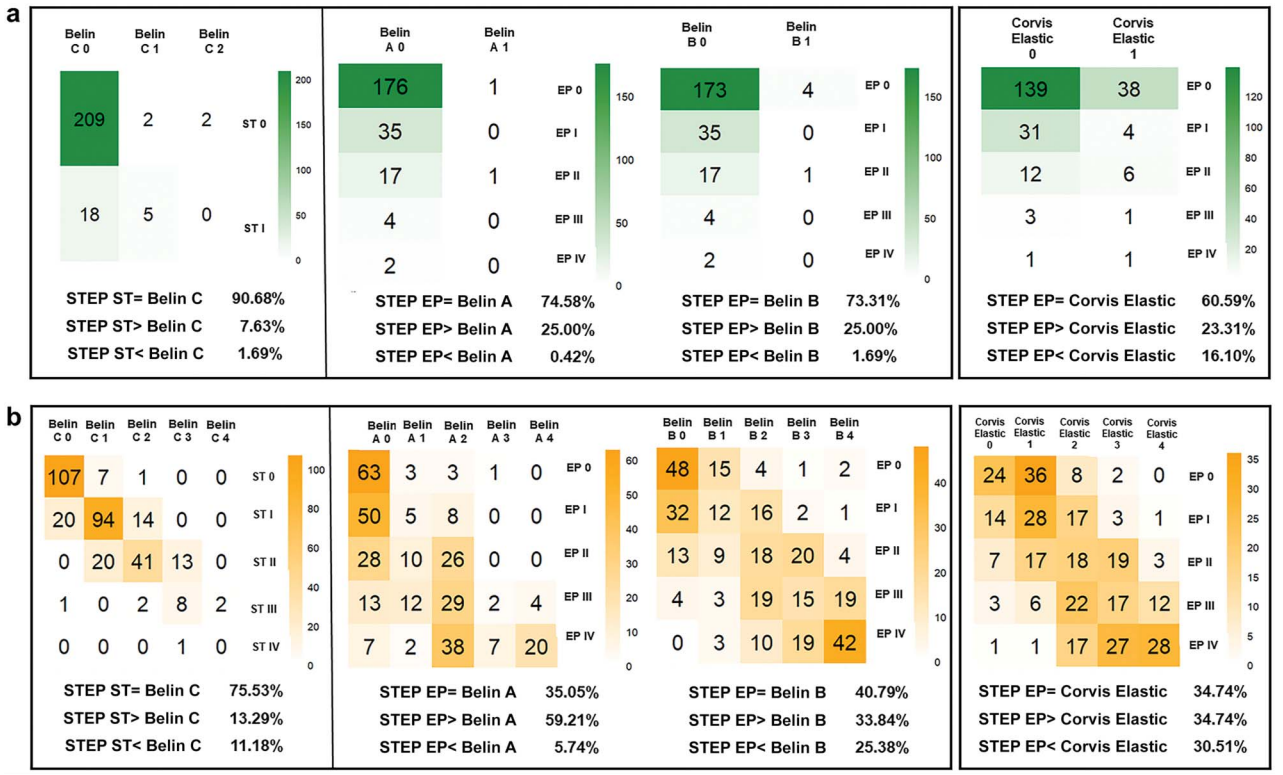

Figure 2. The normal group (*a*) and KC group (*b*) staging distribution in the STEP and Pentacam Belin ABC staging system and Corvis Elastic staging system. KC = keratoconus; STEP EP = Epithelium Overall SD; STEP ST = Stroma Overall Minimum Thickness. The numbers on the left diagonal represent eyes at the same stages in the 2 staging systems, indicated by "=" in the statistics below. The numbers below the left diagonal represent eyes that are more severely staged in the STEP staging system than in another staging system, indicated by ">" in the statistics below. The numbers above the left diagonal represent eyes that are less severely staged in the STEP staging system than in another staging system, indicated by "<" in the statistics below.

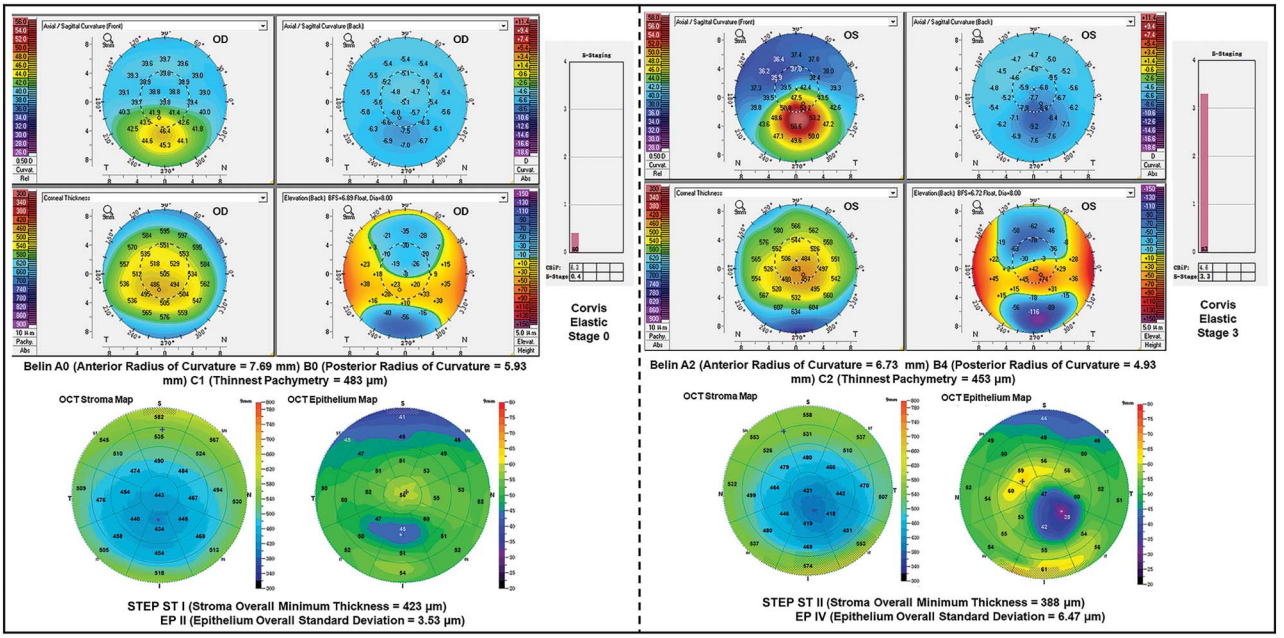

Figure 3. Example cases of two patients with KC in this study. The information of 3 staging systems is presented: For the first patient, the right eye has EKC and left eye has AKC; the Dresden protocol may not be considered for the left eye as the STEP ST parameter is located in stage II. EKC = early-stage KC; FFKC = forme fruste KC; KC = keratoconus; STEP EP = Epithelium Overall Standard Deviation; STEP ST = Stroma Overall Minimum Thickness

with Belin A and B values in the KC group, especially with the former. This could be explained by the fact that the epithelial remodeling occurs before the change in corneal curvature.[40] However, we should note that a good disease grading system should classify most normal patients as stage 0 to 1 and affected patients as higher than stage 0, as we see with the STEP staging system. AS-OCT can also detect the anterior and posterior corneal curvatures simultaneously with good accuracy in both normal patients and patients with KC.[41] Therefore, the STEP staging system has the potential advantage of integrating the Belin ABCD staging system or regard it as a simultaneous reference.

There are some limitations of our study, one of which is that no progressive cases were evaluated with the STEP system. Furthermore, this analysis does not validate the universal application of the STEP system for other types of OCT systems that may lead to slightly different thickness of the corneal layers. Further investigation on this matter is required. In addition, since the STEP system includes an index that relies on a single-point measurement (ST), potential future improvements of commercial AS-OCT systems allowing to determine the profiles of the epithelium and stroma could further improve the reliability of the STEP system.

In conclusion, we propose a digital, automated, and comprehensive OCT-based KC staging system that is compatible with the existing KC staging systems and offers additional clinical relevance. This system could be incorporated into daily clinical practice and in research as it has the potential to help in treatment decision making and monitor KC progression.

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WHAT WAS KNOWN

- There are several staging systems for keratoconus (KC) management based on Scheimpflug tomography or biomechanics.
- OCT provides a high-resolution profile of corneal epithelium and stroma, useful for early diagnosis of KC.

WHAT THIS PAPER ADDS

- A new KC staging system was defined based on OCT, which includes information about the corneal layers.
- The performance of this STEP system is on par with the existing staging systems defined for other clinical devices.
- The STEP system could be used for KC management in clinical practice and research.

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