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Diagnostic Accuracy of Corneal and Epithelial Thickness Map Parameters in Detecting Keratoconus, Subclinical Keratoconus, and Suspect Keratoconus

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Abstract

Purpose. To evaluate the diagnostic efficacy of corneal and epithelial thickness maps generated using anterior segment optical coherence tomography (AS-OCT) in cases of suspected keratoconus, subclinical keratoconus, and keratoconus.

Methods. This prospective study included 41 patients (61 eyes) with suspected keratoconus, 30 patients (30 eyes) with subclinical keratoconus, 23 patients (30 eyes) with keratoconus, and 25 patients (50 eyes) with myopia who underwent corneal refractive surgery in the Refractive Surgery Department of Shanxi Eye Hospital between March 2023 and December 2023. All participants underwent anterior segment optical coherence tomography (AS-OCT) examinations. Key measurements included central corneal thickness (CCT), central epithelial thickness (CET), corneal epithelial thickness in specific areas, corneal thickness mapping parameters, and corneal epithelial thickness mapping parameters, obtained through AS-OCT. The data were analyzed using the Kruskal-Wallis H test or ANOVA, as appropriate. Parameters showing significant differences were further evaluated for diagnostic performance using receiver operating characteristic (ROC) curves.

Results. The S-ET in the normal and suspected groups was thinner than the I-ET, while the S-ET in the keratoconus group was thicker than the I-ET. These differences were statistically significant ($P < 0.05$). ROC curve analysis of the corneal thickness mapping parameters revealed that the diagnostic efficacy (AUC) of S-I CT, Min-Max CT, and SN-IT CT for distinguishing the suspected group from the normal group were 0.85, 0.835, and 0.817, respectively. Similarly, the diagnostic efficacy (AUC) of MIN CT and CCT for differentiating the subclinical group from the normal group were 0.892 and 0.874, respectively. Analysis of corneal epithelial thickness mapping parameters showed that MSD ET had the highest diagnostic efficacy for distinguishing keratoconus from the normal group, with an AUC of 0.91. This was followed by MIN-MAX ET and Min ET, with AUCs of 0.873 and 0.807, respectively.

Conclusion. The corneal thickness mapping parameters obtained through AS-OCT demonstrate exceptional diagnostic accuracy for the suspected, subclinical, and keratoconus groups. Similarly, the corneal epithelial thickness mapping parameters exhibit high diagnostic precision for the keratoconus group and hold notable diagnostic value for the suspected and subclinical groups.

Introduction

Keratoconus is a bilateral, asymmetric corneal ectasia characterized by progressive thinning and steepening of the central or paracentral cornea. These changes result in irregular astigmatism and vision loss, affecting individuals across all races and genders [1, 2]. In advanced stages, the condition can be relatively easily identified using typical slit lamp signs such as the Fleischer ring, Vogt striae, Rizzuti's sign, Munson's sign, or focal corneal swelling and thinning. However, early diagnosis is often challenging, as patients frequently lack distinguishable clinical symptoms or slit lamp findings. Consequently, incorporating additional diagnostic results for auxiliary evaluation becomes essential [3].

Corneal anterior and posterior surface topography has become widely recognized and employed in the early detection of keratoconus. Among the available technologies, Pentacam is the most frequently utilized in clinical practice. One of its key features, the Belin-Ambrosio Enhanced Ectasia Display (BAD), generates a comprehensive index known as the D value, derived from a combination of measurements including corneal anterior and posterior surface elevations, thickness mapping, best-fitting spherical surface calculations, and an enhanced reference plane analysis. This tool serves as a valuable instrument for the auxiliary screening of keratoconus and ectatic corneal diseases, and it is commonly used for preoperative screening in corneal refractive surgeries [4, 5].

Research by Hashemi et al. revealed that the BAD-D index achieves 97% specificity and 83% sensitivity for diagnosing keratoconus [6]. Similarly, Correia et al. confirmed that an abnormal BAD-D value (> 1.6) is the most reliable indicator for detecting early-stage keratoconus [7]. These findings support the hypothesis that keratoconus originates from localized weakening of corneal biomechanical properties (BPs), enabling its identification during the initial phases of biomechanical alterations, prior to the development of morphological changes.

Corneal visualization Scheimpflug technology (Corvis ST, Oculus) is the most widely adopted method for assessing corneal biomechanics. Advances in examination technology have made it possible to integrate Corvis ST analyses with Pentacam tomography data for combined biomechanical and topographical evaluations. This joint approach enhances the accuracy of early keratoconus diagnosis and grading [8, 9]. However, even this combined methodology falls short of achieving 100% sensitivity or specificity for early-stage detection. As a result, the development of additional auxiliary diagnostic methods remains critical for improving the accuracy of early keratoconus identification.

Anterior segment optical coherence tomography (AS-OCT), corneal ultrasound pachymetry, and confocal microscopy are commonly employed to measure corneal thickness. However, both confocal microscopy and corneal ultrasound pachymetry necessitate direct contact with the corneal tissue, rendering them invasive procedures. This not only complicates the operation but also increases the risk of infection to some extent [10]. In contrast, AS-OCT is a non-contact, non-invasive imaging technology offering high-resolution anterior segment imaging. It enables precise measurement of total corneal thickness, as well as the distribution of thickness in the corneal epithelium and stroma, while identifying features such as corneal asymmetry and global or localized thinning. AS-OCT has been extensively utilized in diagnosing keratoconus and other corneal ectasia conditions [11]. Numerous studies have demonstrated that AS-OCT provides excellent repeatability and reliability in measuring corneal thickness across the central, paracentral, and peripheral regions. Additionally, it has been instrumental in monitoring changes in corneal epithelium in keratoconus patients, further underscoring its critical role in diagnosing and evaluating the progression of keratoconus [12, 13].

In this study, we sought to assess corneal and epithelial thickness mapping parameters in cases of keratoconus, subclinical keratoconus, suspected keratoconus, and normal corneas using OPTOVUE OCT.

Additionally, we aimed to identify the metric with superior diagnostic performance for distinguishing suspected keratoconus from subclinical keratoconus.

Patients and Methods

Patients diagnosed with keratoconus, subclinical keratoconus, suspected keratoconus, or myopia who underwent corneal refractive surgery in the Refractive Surgery Department of Shanxi Eye Hospital between March 2023 and December 2023 were included in the study. The study was approved by the Ethics Committee of Shanxi Eye Hospital and conducted in accordance with the Declaration of Helsinki (SXYYLL-KSSC006). Written informed consent was obtained from all participants.

Criteria

The diagnosis of keratoconus is established based on the global consensus on keratoconus [14]. It requires at least one slit lamp sign—such as stromal thinning, Vogt's striae, a Fleischer ring > 2 mm, or corneal scarring—and an asymmetric topographic feature, specifically an inferior-superior difference (I-S value) ≥ 1.9 diopters (D) in the 6 mm area.

Currently, the most widely accepted diagnostic criteria for subclinical keratoconus [15] are as follows: the contralateral eye must be diagnosed with clinical keratoconus, while the ipsilateral eye shows no clinical signs of keratoconus, appearing normal under slit lamp biomicroscopy, corneal measurements, and ophthalmoscopy. Additionally, the corneal topographic pattern must exhibit either a radial axis-tilted bow configuration or an I-S value between 1.4 D and 1.9 D.

The diagnosis of suspected keratoconus requires meeting the following criteria [16]: best-corrected visual acuity (BCVA) ≥ 1.0; a normal cornea as assessed by slit lamp microscopy and ophthalmoscopy; and the presence of at least one independent parameter from the BAD enhanced expansion analysis. These parameters include a deviation in either the front elevation difference map (Df) or the back elevation difference map (Db), with coded values appearing in red (≥ 2.6 standard deviations) or yellow (≥ 1.6 standard deviations). Additionally, the final BAD parameter "D" must be coded yellow, or the height value of the thinnest posterior surface point mapping in Pentacam 4 maps refractive measurements must fall within the range of + 13 to + 16 μm.

Twenty-five healthy subjects (50 eyes) were included in the normal control group. The following exclusion criteria were applied: (1) pregnant or lactating women; (2) individuals with eye diseases other than refractive errors; (3) individuals with systemic conditions such as diabetes, hypertension, or immune deficiencies; (4) individuals with a history of eye surgery; and (5) individuals with serious psychological or mental conditions, including anxiety or depression.

Examination

Each patient underwent a thorough ocular examination, which included retinoscopy, slit-lamp biomicroscopy, uncorrected visual acuity assessment, spherical and cylindrical refraction determined via apparent refraction, as well as evaluations using the Pentacam, Corvis ST, and AS-OCT. All procedures were conducted by the same technician, and the final analysis was based on the average results from three tests that demonstrated high reproducibility.

AS-OCT Parameters: Using the OPTOVUE OCT (IVU100, Colin Instruments, USA), the central corneal thickness (CCT) and central epithelial thickness (CET) were measured in the 0–2 mm area. Additionally, the corneal epithelial thickness was assessed across eight quadrants in the 2–5 mm area: superior (S), supranasal (SN), nasal (N), infranasal (IN), inferior (I), infratemporal (IT), temporal (T), and supratemporal (ST).

The distinction between the mean thickness of the supranasal and infratemporal octants of the cornea (measured 2 to 5 mm from the center) is denoted as SN-IT (2–5 mm) CT. Similarly, the difference in mean thickness between the inferior and superior octants of the cornea (2 to 5 mm from the center) is represented as S-I (2–5 mm) CT. The point of minimum corneal thickness is referred to as MIN CT, while the location of the thinnest point along the vertical meridian is identified as Location Y CT, with positive values indicating positions superior to the corneal vertex and negative values indicating positions inferior to it. Furthermore, the difference between the minimum and median corneal thickness is expressed as Min-Median CT, and the difference between the minimum and maximum corneal thickness is termed Min-Max CT.

The mean thickness of the superior epithelium, measured 2 to 5 mm from the center, is denoted as S (2–5 mm) ET. Similarly, the mean thickness of the inferior epithelium, recorded 2 to 5 mm from the center, is represented as I (2–5 mm) ET. The minimum corneal epithelial thickness is identified as MIN ET, while the maximum corneal epithelial thickness is referred to as MAX ET. The difference between the minimum and maximum corneal epithelial thickness points is expressed as MIN–MAX ET. Lastly, the standard deviation of all epithelial thickness measurements within the central 5 mm of the cornea is defined as Map Std Dev (MSD ET).

Statistical Analysis

SPSS 27.0 software was utilized for data analysis. Quantitative variables were expressed as the mean ± standard deviation. The Kolmogorov-Smirnov and Shapiro-Wilk tests were applied to assess the normality of the variables. Differences among the four groups were analyzed using ANOVA when the data met the assumptions of normal distribution and homogeneity of variance. If these assumptions were not satisfied, the Kruskal-Wallis H test was employed. For intra-group differences in S (2–5 mm) ET and I (2–5 mm) ET, either the Wilcoxon test or the paired sample T-test was conducted. Receiver operating characteristic (ROC) curve analysis was performed for each significant variable to evaluate its diagnostic performance, with the area under the curve (AUC) quantified to determine sensitivity,

specificity, cut-off values, and the Youden index. A p-value of less than 0.05 was considered statistically significant.

Results

The keratoconus group comprised 30 eyes from 23 patients, including 12 males and 11 females, with an average age of 26.78 ± 7.45 years (range: 18–48 years). The subclinical group included 30 eyes from 30 patients, consisting of 21 males and 9 females, with an average age of 25.07 ± 5.69 years (range: 18–37 years). The suspected group encompassed 61 eyes from 41 patients, with 18 males and 23 females, and an average age of 22.71 ± 5.92 years (range: 18–45 years). Finally, the normal group consisted of 50 eyes from 25 patients, comprising 15 males and 10 females, with an average age of 22.44 ± 4.81 years (range: 18–37 years).

The average spherical refraction in the keratoconus, subclinical, suspected, and normal groups was − 5.58 ± 3.38D (range: -16.75 to -1.00D), -5.04 ± 3.04D (range: -11.75 to -1.00D), -5.01 ± 2.38D (range: -10.25 to 0.50D), and − 5.25 ± 1.64D (range: -8.50 to 1.75D), respectively. The average cylindrical refraction for these groups was − 3.8 ± 2.47D (range: -10.00 to -0.75D), -1.64 ± 1.04D (range: -4.25 to -0.25D), -1.26 ± 0.97D (range: -4.75 to 0.00D), and − 1.09 ± 0.72D (range: -2.75 to 0.00D), respectively. While there was no statistically significant difference in average spherical refraction among the four groups (P = 0.731), the cylindrical refraction of the keratoconus group was significantly different compared to the normal, suspected, and subclinical groups (P < 0.05), as summarized in Table 1.

Table 1
Comparison of General Examination Results among Normal Group, Suspected Group, Subclinical Group and Clinical Group

eyes	**Normal Group**	**Suspected Group**	**Subclinical Group**	**Clinical Group**	**P**
	50	**61**	**30**	**30**	
Gender					
male	15	18	21	12	
female	10	23	9	11	
Age(years)	22.44 ± 4.82(18 ~ 37)	22.71 ± 5.92(18 ~ 45)	25.07 ± 5.69(18 ~ 37)	26.78 ± 7.45(18 ~ 48)	0.02
SE(D)	-5.25 ± 1.64(-8.50 ~ 1.75)	-5.01 ± 2.38(-10.25 ~ 0.50)	−5.04 ± 3.04(−11.75~−1.00)	-5.58 ± 3.38(-16.75~-1.00)	0.731
Cylinder(D)	-1.09 ± 0.72(-2.75 ~ 0.00)	-1.26 ± 0.97(-4.75 ~ 0.00)	−1.64 ± 1.04(−4.25~−0.25)	-3.8 ± 2.47(-10.00~-0.75)	< 0.001

P < 0.05 indicates statistically significant differences.

The details of the central corneal thickness and corneal thickness mapping parameters are summarized in Table 2. In the normal group, the following measurements were recorded: SN-IT (2–5 mm) CT at 14.92 ± 11.34 μm, S-I (2–5 mm) CT at 10.66 ± 10.95 μm, MIN CT at 538.72 ± 23.16 μm, Location Y CT at -231.74 ± 283.33 μm, Min-Median CT at -24.44 ± 3.63 μm, Min-Max CT at -57.48 ± 10.46 μm, and CCT at 544.04 ± 23.64 μm. Statistically significant differences (P 0.05) were found in any of the corneal thickness mapping parameters when comparing the suspected group with the subclinical group.

The detailed data analysis of corneal epithelial thickness and corneal epithelial thickness mapping parameters is presented in Table 2. Comparisons among the four groups revealed that, with the exception of 2-5mm (IN), all other indicators demonstrated statistically significant differences (P 0.05).

Table 2
The details of the central corneal thickness and corneal thickness mapping parameters

parameters	Normal Group	Suspected Group	Subclinical Group	Clinical Group	P values	Suspected VS Subclinical P values
CCT(0−2mm)	544.04 ± 23.64	516.11 ± 35.56[a]	495.67 ± 33.94[a]	468.1 ± 36.19[a]	< 0.001	0.129
SN-IT(2 ~ 5MM) CT	14.92 ± 11.34	30.02 ± 11.36[a]	26.03 ± 20.89[a]	46.5 ± 26.48[a]	< 0.001	1
S-I(2 ~ 5MM) CT	10.66 ± 10.95	27.25 ± 11.55[a]	23.07 ± 20.41[a]	42.77 ± 22.96[a]	< 0.001	0.939
MIN CT	538.72 ± 23.16	508.79 ± 35.45[a]	485.97 ± 34.42[a]	448.43 ± 36.34[a]	< 0.001	0.098
Location Y CT	−231.74 ± 283.33	−406.23 ± 173.85[a]	−492.57 ± 520.87[a]	−732.90 ± 431.61[a]	< 0.001	1
Min-Median CT	−24.44 ± 3.63	−28.31 ± 3.48[a]	−29.30 ± 10.17	−45.07 ± 13.60[a]	< 0.001	1
Min-Max CT	−57.48 ± 10.46	−71.97 ± 10.56[a]	−71.07 ± 19.06[a]	−96.67 ± 25.81[a]	< 0.001	1
CET(0−2mm)	53.12 ± 3.24	52.54 ± 3.63	54.27 ± 3.70	50.30 ± 5.09[a]	0.002	0.178
S(2−5mm) ET	51.12 ± 3.38	49.92 ± 3.78	54.67 ± 4.12[a]	54.77 ± 4.27[a]	< 0.001	0
I(2−5mm)ET	54.06 ± 3.68	52.62 ± 3.44	54.90 ± 3.53	52.40 ± 4.39	0.005	0.014
Min ET	47.66 ± 2.92	45.64 ± 4.75	48.67 ± 4.79	43.43 ± 5.24[a]	< 0.001	0.018
MAX ET	57.18 ± 3.97	55.95 ± 3.69	59.17 ± 4.23	62.13 ± 5.45[a]	< 0.001	0.004
MIN-MAX ET	−9.52 ± 3.34	−10.31 ± 4.66	-10.57 ± 5.87	−18.77 ± 7.16[a]	< 0.001	1

parameters	Normal Group	Suspected Group	Subclinical Group	Clinical Group	P values	Suspected VS Subclinical P values
MSD ET	1.96 ± 0.74	2.12 ± 0.85	2.45 ± 1.66	4.65 ± 1.94[a]	< 0.001	1
2 ~ 5mm ET						
Superior	52.08 ± 3.55	51.43 ± 3.58	54.17 ± 3.93	55.70 ± 4.45[a]	< 0.001	0.009
SN	52.68 ± 3.32	52.02 ± 3.60	54.73 ± 4.03	55.07 ± 4.54	0.001	0.009
Nasal	53.46 ± 3.28	52.77 ± 3.50	55.67 ± 4.06	55.23 ± 5.53	0.004	0.005
IN	54.3 ± 3.62	53.33 ± 3.52	55.40 ± 3.78	54.07 ± 5.08	0.051	0.231
Inferior	54.2 ± 3.76	52.82 ± 3.53	54.17 ± 4.25	51.53 ± 4.99[a]	0.008	0.199
IT	53.80 ± 3.76	52.41 ± 3.70	53.83 ± 4.53	49.03 ± 5.34[a]	< 0.001	0.001
Temporal	53.34 ± 3.42	52.10 ± 3.58	55.37 ± 3.93	52.03 ± 5.68	< 0.001	0.000
ST	52.50 ± 3.35	51.70 ± 3.77	55.23 ± 3.98[a]	55.70 ± 5.40[a]	< 0.001	

CCT (0-2mm), central corneal thickness in the 0-2mm region; SN-IT (2-5mm) CT, the difference between the mean thickness of supranasal and infratemporal octants of the cornea (2 to 5 mm from the center); S-I (2-5mm) CT,the difference between the mean thickness of the inferior and superior octants of the cornea (2 to 5 mm from the center); MIN CT, the minimum corneal thickness ; Location Y CT,the location of the thinnest point in the vertical meridian (positive values for locations superior to the corneal vertex; negative values for locations inferior to the corneal vertex); Min-Median CT, the difference between the minimum and the median corneal thickness point; Min-Max CT,the difference between the minimum and the maximum corneal thickness point; CET (0-2mm), central epithelial thickness in the 0-2mm region; S (2-5mm) ET, the mean of thickness values recorded in the superior epithelium (2 to 5 mm from the center); I (2-5mm) ET,the mean of thickness values recorded in the inferior epithelium (2 to 5 mm from the center); Min ET, the minimum corneal epithelial thickness point; MAX ET, the maximum corneal epithelial thickness point; MIN-MAX ET, the difference between the minimum and the maximum corneal epithelial thickness point; MSD ET, the standard deviation of all epithelial thicknesses mapping recorded in the central 5 mm of the cornea;P < 0.05, statistically significant difference ; [a], indicates that the difference is statistically significant (P < 0.05) compared with the normal group.

In comparison with the subclinical group, the S(2-5mm) ET and 2-5mm (ST) values in the normal group were significantly thinner than those in the subclinical group (P < 0.05). Compared with the keratoconus group, the S(2-5mm) ET, MAX ET, MSD ET, and 2-5mm (ST) values in the normal group were significantly smaller, whereas the MIN ET, MIN-MAX ET, CET, 2-5mm (S), 2-5mm (I), and 2-5mm (IT) values in the normal group were significantly larger (P < 0.05). Further intra-group comparisons of corneal epithelial thickness mapping parameters (S(2-5mm) ET and I(2-5mm) ET) across the four groups yielded significant findings. The S(2-5mm) ET of the normal group and suspected group was markedly thinner than their corresponding I(2-5mm) ET, with highly significant differences (P < 0.001). Conversely, in the keratoconus group, the S(2-5mm) ET was significantly thicker than the I(2-5mm) ET, also with statistical significance (P = 0.004). However, no statistically significant difference was noted between the S(2-5mm) ET and I(2-5mm) ET values in the subclinical group (P = 0.257), as shown in Table 3.

Table 3
Intra-group comparisons of S (2–5 mm) ET and I (2–5 mm) ET across four groups

group	P value	S(2–5mm) ET-I(2–5mm) ET	S(2–5mm) ET-I(2–5mm) ET
		M	SD
Normal	<0.001	−2.94	2.60
Suspected	<0.001	−2.71	2.72
Subclinical	0.257		
Clinical	0.004	2.37	4.13

M,mean value;SD,Standard deviation;S (2-5mm) ET, the mean of thickness values recorded in the superior epithelium (2 to 5 mm from the center); I (2-5mm) ET, the mean of thickness values recorded in the inferior epithelium (2 to 5 mm from the center); P < 0.05 indicates statistically significant differences.

For central corneal thickness and corneal thickness mapping parameters, the diagnostic efficacy AUC of S-I (2–5 mm) CT was 0.85. The diagnostic efficacy AUCs for Min-Max CT and SN-IT (2–5 mm) CT were 0.835 and 0.817, respectively, while the AUCs for other parameters ranged from 0.716 to 0.79, as illustrated in Table 4 and Fig. 1. For the comparison between the normal group and the subclinical group, the diagnostic efficacy AUCs for MIN CT and CCT were 0.892 and 0.874, while the AUCs for other parameters ranged from 0.645 to 0.714, as displayed in Table 5 and Fig. 2. For the comparison between the normal group and the keratoconus group, except for Location Y CT (AUC = 0.852, cutoff value = -552.5, sensitivity = 70.00%, specificity = 94.00%), the diagnostic efficacy AUCs for CCT and other corneal thickness mapping parameters were ≥ 0.90, as demonstrated in Table 6. For the comparison between the suspected group and the subclinical group, MIN CT and CCT showed moderate diagnostic efficacy, with AUCs of 0.72 and 0.706, respectively, as presented in Table 7.

Table 4
Diagnostic efficacy of corneal thickness parameters versus epithelial thickness parameters in distinguishing between suspicious and normal groups

parameters	AUC	Sensitivity(%)	Specitivity(%)	Cutoff value
CCT(0 ~ 2MM)	0.745	82.00	66.00	542.5
SN-IT(2 ~ 5MM)CT	0.817	80.3	68	20.5
S-I(2 ~ 5MM)CT	0.85	59	94	25.5
MIN CT	0.755	80.3	68	535.5
Location Y CT	0.716	73.8	66	−357.5
Min-Median CT	0.79	80.3	68	−25.5
Min-Max CT	0.835	65.6	84	−67.5
I(2−5mm) ET	0.619	54.1	68	52.5
Min ET	0.662	70.5	58	47.5

CCT (0-2mm), central corneal thickness in the 0-2mm region; SN-IT (2-5mm) CT, the difference between the mean thickness of supranasal and infratemporal octants of the cornea (2 to 5 mm from the center); S-I (2-5mm) CT,the difference between the mean thickness of the inferior and superior octants of the cornea (2 to 5 mm from the center); MIN CT, the minimum corneal thickness ; Location Y CT,the location of the thinnest point in the vertical meridian (positive values for locations superior to the corneal vertex; negative values for locations inferior to the corneal vertex); Min-Median CT, the difference between the minimum and the median corneal thickness point; Min-Max CT,the difference between the minimum and the maximum corneal thickness point; I (2-5mm) ET,the mean of thickness values recorded in the inferior epithelium (2 to 5 mm from the center); Min ET, the minimum corneal epithelial thickness point; P < 0.05 indicates statistically significant differences.

Table 5
Corneal thickness and epithelial thickness parameters distinguish subclinical from normal groups with diagnostic efficacy

parameters	AUC	Sensitivity(%)	Specitivity(%)	Cutoff value
CCT(0 ~ 2MM)	0.874	80	88	518
MIN-MAX CT	0.705	40	100	-75
SN-IT(2 ~ 5MM)CT	0.714	53.3	82	26.5
S-I(2 ~ 5MM)CT	0.692	43.3	96	28.5
MIN CT	0.892	83.3	88	514
Location Y CT	0.645	0.433	0.92	-536
Min-Median CT	0.645	63.3	68	-25.5
S(2−5mm) ET	0.759	66.7	74	53.5
MAX ET	0.644	76.7	50	56.5

CCT (0-2mm), central corneal thickness in the 0-2mm region; SN-IT (2-5mm) CT, the difference between the mean thickness of supranasal and infratemporal octants of the cornea (2 to 5 mm from the center); S-I (2-5mm) CT,the difference between the mean thickness of the inferior and superior octants of the cornea (2 to 5 mm from the center); MIN CT, the minimum corneal thickness ; Location Y CT,the location of the thinnest point in the vertical meridian (positive values for locations superior to the corneal vertex; negative values for locations inferior to the corneal vertex); Min-Median CT, the difference between the

minimum and the median corneal thickness point; Min-Max CT,the difference between the minimum and the maximum corneal thickness point;;S (2-5mm) ET, the mean of thickness values recorded in the superior epithelium (2 to 5 mm from the center); *MAX ET, the maximum corneal epithelial thickness point; P < 0.05 indicates statistically significant differences.*

Table 6
Corneal thickness and epithelial thickness parameters distinguish clinical from normal groups with diagnostic efficacy

parameters	AUC	Sensitivity(%)	Specitivity(%)	Cutoff value
CCT(0 ~ 2MM)	0.949	80	100	494
SN-IT(2 ~ 5MM)CT	0.9	80	98	35
S-I(2 ~ 5MM)CT	0.926	90	92	24.5
MIN CT	0.963	96.7	92	504.5
Location Y CT	0.852	70	94	-552.5
Min-Median CT	0.987	96.7	92	-29.5
Min-Max CT	0.975	83.3	100	-74.5
S(2−5mm)ET	0.750	100	100	0.745
MIN ET	0.807	66.7	84	44.5
MAX ET	0.790	83.3	66	58.5
MSD ET	0.910	86.7	90	2.75
MIN-MAX ET	0.873	83.3	88	-12.5
CET(0 ~ 2MM)	0.698	70.0	70.0	51.5

CCT (0-2mm), central corneal thickness in the 0-2mm region; SN-IT (2-5mm) CT, the difference between the mean thickness of supranasal and infratemporal octants of the cornea (2 to 5 mm from the center); S-I (2-5mm) CT,the difference between the mean thickness of the inferior and superior octants of the cornea (2 to 5 mm from the center); MIN CT, the minimum corneal thickness ; Location Y CT,the location of the thinnest point in the vertical meridian (positive values for locations superior to the corneal vertex; negative values for locations inferior to the corneal vertex); Min-Median CT, the difference between the minimum and the median corneal thickness point; Min-Max CT,the difference between the minimum and the maximum corneal thickness point; CET (0-2mm), central epithelial thickness in the 0-2mm region; S (2-5mm) ET, the mean of thickness values recorded in the superior epithelium (2 to 5 mm from the center); I (2-5mm) ET,the mean of thickness values recorded in the inferior epithelium (2 to 5 mm from the center); Min ET, the minimum corneal epithelial thickness point; MAX ET, the maximum corneal epithelial thickness point; MIN-MAX ET, the difference between the minimum and the maximum corneal epithelial thickness point; MSD ET, the standard deviation of all epithelial thicknesses mapping recorded in the central 5 mm of the cornea;P < 0.05, statistically significant difference

Table 7
Diagnostic efficacy of corneal thickness parameters versus epithelial thickness parameters in distinguishing subclinical groups from suspected cases

parameters	AUC	Sensitivity(%)	Specitivity(%)	Cutoff value
CCT	0.706	76.7	64.3	515
MIN CT	0.72	80	64.3	507.5
S(2−5mm) ET	0.812	90	62.3	50.5
I(2−5mm) ET	0.697	73.3	63.9	53.5
Min ET	0.689	60	80.3	48.5
MAX ET	0.725	76.7	63.9	56.5

CCT (0-2mm), central corneal thickness in the 0-2mm region; MIN CT,the minimum corneal thickness point; S (2-5mm) ET, the mean of thickness values recorded in the superior epithelium (2 to 5 mm from the center); I (2-5mm) ET,the mean of thickness values recorded in the inferior epithelium (2 to 5 mm from the center);Min ET, the minimum corneal epithelial thickness point

Regarding central corneal epithelial thickness and corneal epithelial thickness mapping parameters, the diagnostic efficacy AUC of Min ET was 0.662, with sensitivity and specificity of 70.50% and 58.00%, respectively, as displayed in Table 4 and Fig. 3. For the comparison between the normal group and the subclinical group, the diagnostic efficacy AUC for S (2–5 mm) ET was 0.759, as illustrated in Table 5 and Fig. 4. For the comparison between the normal group and the keratoconus group, the diagnostic efficacy AUC for MSD ET was 0.91, with sensitivity of 86.70%, specificity of 90%, and a cutoff value of 2.75. The diagnostic efficacy AUCs for other corneal epithelial thickness parameters were all below 0.90, as shown in Table 6 and Fig. 5. In the comparison between the suspected group and the subclinical group, S (2–5 mm) ET demonstrated soliddiagnostic efficacy, with an AUC of 0.812, a cutoff value of 50.5, sensitivity of 90.00%, and specificity of 62.30%, as presented in Table 7.

Discussion

Currently, the number of myopia patients in China has reached an astonishing 600 million. Projections suggest that by 2050, nearly 50% of the global population will be affected by myopia. Driven by both functional and cosmetic demands, an increasing number of individuals are opting for corneal refractive surgery. Although advancements in corneal refractive surgery have significantly improved its precision and safety, postoperative complications still occur. Among these, the most severe is secondary keratoconus, a condition that impairs vision and, in extreme cases, necessitates corneal transplantation.

The primary cause of postoperative secondary keratoconus lies in the failure to identify patients with a predisposition to keratoconus before surgery. As such, keratoconus is considered an absolute contraindication for corneal refractive surgery, making preoperative screening vital to preventing serious

complications. Keratoconus is a progressive corneal disease characterized by corneal thinning and protrusion. Histopathologically, it is marked by thinning of the corneal stroma, degradation of the epithelial basement membrane, and a reduction in both the density and quantity of collagen fibers.

The exact mechanism behind keratoconus remains unclear, but some studies suggest that it arises from relative displacement or slippage between layers of corneal collagen fibers, leading to corneal thinning. Additionally, increased levels of catabolic enzymes, such as protein kinase, and decreased levels of protein kinase inhibitors within corneal tissue contribute to the condition. These enzymatic imbalances, coupled with intraocular pressure (IOP)-induced stress, result in corneal protrusion, biomechanical instability, and a reduction in mechanical strength. Consequently, both corneal tissue thinning and altered biomechanics play essential roles in the pathogenesis of keratoconus.

Currently, there is no universally accepted standard for the classification and definition of preclinical keratoconus. The medical literature broadly categorizes it into several subtypes, including suspected keratoconus, subclinical keratoconus, forme fruste keratoconus, and early keratoconus. The classification of suspected keratoconus, in particular, remains contentious. While some scholars classify it as a normal corneal variation, others consider it an early stage of keratoconus. Building on previous research, this study sought to delve deeper into the distinctions between suspected and subclinical keratoconus, identifying their differences from normal corneas and evaluating sensitive diagnostic indicators.

In this study, the inclusion criteria for subclinical keratoconus encompassed the contralateral eye of patients with unilateral keratoconus. For suspected keratoconus, the inclusion criteria were based on the posterior elevation map from Pentacam corneal topography and the deviation values derived from Belin analysis. Through these parameters, the study aimed to refine diagnostic approaches and improve the identification of preclinical keratoconus.

In this study, the central corneal thickness (CCT) values for the normal, suspected, subclinical, and keratoconus groups were 544.04 ± 23.64 μm, 516.11 ± 35.56 μm, 495.67 ± 33.94 μm, and 468.1 ± 36.19 μm, respectively. The CCT of the normal group was significantly thicker than that of the other three groups. These findings closely align with those reported by Catalán et al. for normal corneal CCT (537.6 ± 30.66 μm). However, our results differ from their findings for subclinical keratoconus (513.11 ± 31.90 μm) and keratoconus (482.90 ± 30.62 μm), which could be attributed to variations in ethnicity, sample size, classification criteria for subclinical keratoconus, and differences in keratoconus staging [18].

Parameters such as Min-Median CT, Min-Max CT, and Min CT were identified as indicators of localized corneal thinning. In this study, Min-Median CT, Min-Max CT, and Min CT demonstrated the highest diagnostic performance for distinguishing keratoconus from normal corneas, with area under the curve (AUC) values of 0.987, 0.975, and 0.963, respectively. There were no statistically significant differences in the pairwise comparison of receiver operating characteristic (ROC) curves ($P > 0.05$), which mirrors the findings of Hashemi et al. [19].

For distinguishing the subclinical group from the normal group, MIN CT (AUC = 0.892; cutoff value = 514 μm; sensitivity = 83.3%; specificity = 88.0%) and CCT (AUC = 0.874; cutoff value = 518 μm; sensitivity = 80.0%; specificity = 88.0%) showed the best diagnostic performance. In the subclinical and keratoconus groups, all parameters except MIN CT, Location Y CT, and CCT showed statistically significant differences, consistent with the results reported by Catalán et al. [18].

Additionally, we included a suspected group in the analysis and found that, compared with the normal group, the parameters S-I (2–5 MM) CT, Min-Max CT, and SN-IT (2–5 MM) CT demonstrated good diagnostic efficacy. The respective AUC values for these parameters were 0.850, 0.835, and 0.817, with cutoff values of 25.5, − 67.5, and 20.5. The sensitivities were 59.0%, 65.6%, and 80.3%, while the specificities were 94.0%, 84.0%, and 68.0%. Pairwise comparisons of the ROC curves revealed no statistically significant differences ($P > 0.05$).

Furthermore, this study observed that irregular parameters (reflecting asymmetric thinning of the cornea) in the suspected, subclinical, and keratoconus groups were significantly higher than in the normal group. Specifically, the average thickness difference of the superior–inferior cornea (S-I [2–5 MM] CT) and the supranasal–infratemporal cornea (SN-IT [2–5 MM] CT) were elevated, particularly in the keratoconus group. However, no significant differences were found between the suspected and subclinical groups ($P > 0.05$).

These findings confirm that the distribution of total corneal thickness changes progressively as the cornea transitions from a normal to a diseased state. This provides robust evidence for diagnosing suspected and subclinical keratoconus.

Studies have revealed that the corneal epithelium plays a crucial role in modifying the corneal thickness profile, reconstructing a smooth and symmetric optical surface, and partially or completely masking irregularities on the corneal stromal surface. Notably, changes in corneal epithelial thickness occur earlier than alterations on the anterior surface of the cornea, making the evaluation of epithelial thickness particularly valuable in diagnosing keratoconus [20].

As part of this study, corneal epithelial thickness (CET) and mapping parameters were measured across groups classified as normal cornea, suspected keratoconus, subclinical keratoconus, and keratoconus. The results indicated that CET values for the normal, suspected, subclinical, and keratoconus groups were 53.12 ± 3.24 μm, 52.54 ± 3.63 μm, 54.27 ± 3.70 μm, and 50.30 ± 5.09 μm, respectively. Among these, the keratoconus group exhibited significantly thinner CET compared to the normal group, while no significant differences were observed for the suspected and subclinical groups. These findings closely align with the observations of Li et al. [20], who reported a CET of 54.60 ± 4.25 μm for normal corneas, and Reinstein et al. [21], who reported 52.3 ± 3.6 μm for normal corneas. However, there were discrepancies with the results of Alberto et al. [22], who reported a CET of 42.8 ± 0.5 μm for normal corneas, and with Reinstein et al. [21], who found a CET of 45.7 ± 5.9 μm for keratoconus. These differences may stem from methodological variations: Alberto et al.'s study excluded tear film thickness

from their measurements, and Reinstein et al. included keratoconus cases at all stages, while this study focused specifically on stage 1 or 2 keratoconus cases.

Our analysis further demonstrated that in the 2–5 mm zone, the superior (S) epithelial thickness (ET) in the normal group was significantly thinner than the inferior (I) ET, with a statistically significant difference ($p < 0.001$). This finding aligns with studies by Rattan et al. [23] and Vega et al. [24], which reported similar observations: the superior CET of normal corneas tends to be thinner than the inferior CET. This disparity is thought to result from the mechanical friction and wear exerted by the movement of the upper eyelid, which applies greater force to the superior corneal epithelium.

In the suspected keratoconus group, we observed similar trends: the S (2–5 mm) ET was thinner than the I (2–5 mm) ET, indicating a distribution pattern of thinner epithelium superiorly and thicker epithelium inferiorly. This difference was statistically significant ($p < 0.001$). However, there was no significant difference in ET in any quadrant of the 2–5 mm zone between the normal and suspected keratoconus groups. This lack of statistical significance may be attributed to the inclusion of both normal and preclinical corneas in the suspected keratoconus group, the small sample size, and the multiple subgroup classifications.

In the subclinical keratoconus group, no statistically significant difference was found between S (2–5 mm) ET and I (2–5 mm) ET ($p = 0.257$). Conversely, in the keratoconus group, the S (2–5 mm) ET was significantly thicker than the I (2–5 mm) ET, with a statistically significant difference ($p = 0.004$). This pattern, which deviated from that of the normal group, suggests that the corneal epithelial thickness distribution shifts progressively with disease advancement. Additionally, the infratemporal epithelial thickness in the 2–5 mm zone of the keratoconus group was markedly thinner than that of the normal, suspected, and subclinical groups. This observation aligns with the findings of Serrao et al. [25], whose study highlighted the utility of optical coherence tomography (OCT) in monitoring corneal epithelial changes in keratoconus, particularly in the paracentral (2–5 mm) region. The study suggested that irregularities and asymmetry in epithelial thickness are key diagnostic markers for keratoconus.

These findings further corroborate the epithelial compensation mechanism proposed by Reinstein et al. [21], which describes a localized thinning of the epithelium in keratoconus—often in the paracentral infratemporal region—surrounded by a thickened epithelial ring. Moreover, the study indicated that in more advanced keratoconus cases, the epithelium overlying the cone becomes progressively thinner, while the surrounding epithelium thickens. This suggests that the degree of epithelial compensation may correlate with the severity of keratoconus.

MIN ET, MAX ET, and MIN-MAX ET reflect localized variations in corneal epithelial thickness. Catalan et al. [18] observed that the values for these three parameters in normal corneas closely aligned with our study, whereas Reinstan et al. [21] reported differing values for keratoconus—MIN ET (38.2 ± 5.8 μm), MAX ET (66.8 ± 7.2 μm), and MIN-MAX ET (-28.6 ± 10.8 μm)—which may be attributed to the inclusion of keratoconus at varying stages. In our study, the parameter with the highest diagnostic efficacy for distinguishing between the normal group and the keratoconus group was MSD ET (AUC = 0.910, cutoff

value 2.75, sensitivity 86.7%, specificity 90.0%), followed by MIN-MAX ET (AUC = 0.873, cutoff value −12.5, sensitivity 83.3%, specificity 88.0%). These findings are consistent with those of Li et al. [20], who reported similar results (MSD ET: AUC = 0.89, MIN-MAX ET: AUC = 0.88). These results firmly demonstrate that corneal epithelial thickness changes significantly in keratoconus and highlight the importance of parameter cutoff values in distinguishing between the two groups.

In our analysis, we found that S(2-5mm) ET had the highest diagnostic efficacy for differentiating between the subclinical and normal groups, with an AUC of 0.759, a cutoff value of 53.5, sensitivity of 66.7%, and specificity of 74.0%. MAX ET followed, albeit with a lower diagnostic efficacy, reflected by an AUC of 0.644. Xu et al. [26] reported that corneal epithelial thickness parameters derived from UHR-OCT, namely EEI-MAX (%) and EEI (%), exhibited strong diagnostic efficacy for subclinical keratoconus (AUC > 0.90). The discrepancy between Xu et al.'s findings and ours may stem from differing inclusion criteria for subclinical keratoconus as well as divergent corneal epithelial thickness parameters obtained using varying research instruments.

Further analysis of corneal epithelial thickness mapping parameters for suspected keratoconus revealed that Min ET and I(2-5mm) ET demonstrated the highest diagnostic efficacy compared to the normal group, with AUC values of 0.662 and 0.619, respectively. These findings align with Salman et al. [27], who noted that MIN-MAX ET had the highest diagnostic efficacy, followed by SN-IT ET and MIN ET, albeit with AUC values ranging from 0.653 to 0.707, indicating limited diagnostic performance. This study underscores the diagnostic value of corneal epithelial thickness mapping parameters derived from OPTOVUE OCT in keratoconus cases. Moreover, these parameters hold auxiliary diagnostic significance for suspected and subclinical keratoconus, though they must be integrated with other preoperative screening indicators to enhance diagnostic accuracy.

The study has several limitations. First, the sample size is small, and various indicators lack validation. Consequently, future research with larger sample sizes and follow-up studies is needed to verify the diagnostic indicators and investigate whether a relationship exists between the progression of keratoconus and changes in these indicators. Second, our evaluation of total corneal thickness is restricted to central corneal thickness (CCT) and corneal thickness map parameters, without encompassing the total corneal thickness of individual regions. Additionally, the analysis of corneal epithelial thickness is primarily confined to a 5mm diameter, which may be insufficient for capturing the full spectrum of thickness changes. Expanding the study to encompass the entire cornea could yield more comprehensive and accurate results. Third, long-term follow-up of individuals with suspected keratoconus should be conducted to identify cases that progress to keratoconus, allowing for retrospective analysis of changes and characteristics associated with disease development.

In summary, the corneal thickness mapping parameters proposed in our study demonstrate high sensitivity and specificity in distinguishing clinical keratoconus, subclinical keratoconus, suspected keratoconus, and normal eyes. However, reliance on a single corneal epithelial thickness parameter shows limited diagnostic efficacy for subclinical and suspected keratoconus cases.

Conclusion

In conclusion, corneal and corneal epithelial thickness mapping are valuable tools for refractive surgeons. As these parameters change to varying degrees with the pathological progression of keratoconus, they hold particular advantages for the early detection and monitoring of disease progression.

Declarations

Author Contributions

Study concept and design(ZJ, YG);data collection(ZJ, YG); analysis and interpretation of data (ZJ); writing the manuscript (ZJ, YG); critical revision of the manuscript (ZJ, YG,YF,MQ); administrative, technical, or material support (YF, MQ); supervision (YG,YF,MQ)

Human Ethics and Consent to Participate declarations

This retrospective comparative case series was conducted at the Shanxi Eye Hospital. The study was approved by the Ethics Committee of Shanxi Eye Hospital and conducted in accordance with the Declaration of Helsinki（SXYYLL-KSSC006）. Written informed consent was obtained from all participants.

Consent for publication

Written informed consent was obtained from all participants

Competing interests

The authors declare no competing interests.

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References

1. Krachmer, J.H., Feder, R.S., and Belin, M.W. Keratoconus and related non-inflammatory corneal thinning disorders [J]. *Survey of Ophthalmology*, 1984, 28(4): 293–322.
2. Santodomingo-Rubido J., Carracedo G., Suzaki A., et al. Keratoconus: An Updated Review. *Contact Lens and Anterior Eye*, 2022, Article ID: 101559.
3. Yang Y, Pavlatos E, Chamberlain W, et al. Detection of keratoconus utilizing OCT-derived corneal and epithelial thickness map parameters and patterns [J]. *Journal of Cataract and Refractive Surgery*,

2021, 47(6): 759.

4. Belin, M.W., Jang, H.S., & Borgstrom, M. "Keratoconus: Diagnosis and Staging" [J]. *Cornea*, 2022, 41(1): 1–11.
5. Imbornoni, L. M., McGhee, C. N. J., and Belin, M. W. "The Evolution of Keratoconus: From Diagnosis to Therapeutics" [J]. *Klinische Monatsblätter für Augenheilkunde*, 2018, 235(6): 680–688.
6. Hashemi, H., Beiranvand, A., Yekta, A., et al. "Pentacam Top Indices for Diagnosing Subclinical and Definite Keratoconus" [J]. *Journal of Current Ophthalmology*, 2016, 28(1): 21–26.
7. Correia, F. F., Ramos, I., Lopes, B., et al. "Topometric and Tomographic Indices for the Diagnosis of Keratoconus" [J]. *International Journal of Keratoconus and Ectatic Corneal Diseases*, 2012, 1(2): 92–99.
8. Heidari Z, Hashemi H, Mohammadpour M, et al. A comprehensive three-device study on corneal topographic, tomographic, and biomechanical indices for detecting clinical and subclinical keratoconus [J]. *International Journal of Ophthalmology*, 2021, 14(2): 228.
9. Here is the polished version of the content you provided:Ambrósio Jr. R., Lopes B. T., Faria-Correia F., et al. *Integration of Scheimpflug-Based Corneal Tomography and Biomechanical Assessments to Enhance Ectasia Detection* [J]. *Journal of Refractive Surgery*, 2017, 33(7): 434–443.
10. Reinstein, D. Z., Archer, T. J., Gobbe, M., et al. Epithelial thickness of the normal cornea: Three-dimensional visualization using very high-frequency ultrasound [J]. *Journal of Refractive Surgery* (Thorofare, NJ: 1995), 2008, 24(6): 571.
11. Ramos J. L. B., Li Y., Huang D. **Clinical and research applications of anterior segment optical coherence tomography: A review** [J]. *Clinical & Experimental Ophthalmology*, 2009, 37(1): 81–89.
12. Sin S and Simpson T L conducted a study on the reliability of corneal and corneal epithelial thickness measurements using optical coherence tomography. The findings were published in *Optometry and Vision Science* in 2006, volume 83, issue 6, on pages 360–365.
13. Ma X. J., Wang L., and Koch D. D. examined the repeatability of corneal epithelial thickness measurements using Fourier-domain optical coherence tomography in both normal and post-LASIK eyes [J]. *Cornea*, 2013, 32(12): 1544.
14. Gomes, J. A. P., Tan, D., Rapuano, C. J., et al. "Global Consensus on Keratoconus and Ectatic Diseases" [J]. *Cornea*, 2015, 34(4): 359–369.
15. Izquierdo, Luis Jr., Henriquez, Maria A., and Hadid, Marta. "A Systematic Review of Subclinical Keratoconus and Forme Fruste Keratoconus" [J]. *Journal of Ophthalmology*, 2020, 36(4): 270.
16. Li Y, Xu Z, Liu Q, and colleagues. The correlation between corneal biomechanical parameters and the thickness of corneal sublayers, as measured by Corvis ST and UHR-OCT, in both keratoconus-affected and normal eyes [J]. *Eye and Vision*, 2021, 8(1): 1–12.
17. Gefen, A., Shalom, R., Elad, D., et al. "Biomechanical Analysis of the Keratoconic Cornea" [J]. *Journal of the Mechanical Behavior of Biomedical Materials*, 2009, 2(3): 224–236.

18. Catalan S, Cadarso L, Esteves F, et al. Evaluation of corneal epithelial thickness in asymmetric keratoconic eyes and normal eyes using Fourier-domain optical coherence tomography [J]. *Journal of Ophthalmology,* 2016, Vol. 2016.
19. Hashemi, H., Heidari, Z., Mohammadpour, M., et al. **Distribution Pattern of Total Corneal Thickness in Keratoconus Versus Normal Eyes Using Optical Coherence Tomography** [J]. *Journal of Current Ophthalmology*, 2022, 34(2): 216.
20. Li Y, Tan O, Brass R, et al. **"Corneal Epithelial Thickness Mapping by Fourier-Domain Optical Coherence Tomography in Normal and Keratoconic Eyes"** [J]. *Ophthalmology*, 2012, 119(12): 2425–2433.
21. Reinstein D. Z., Gobbe M., Archer T. J., et al. Epithelial, stromal, and total corneal thickness in keratoconus: three-dimensional visualization using Artemis very-high-frequency digital ultrasound [J]. *Journal of Refractive Surgery,* 2010; 26(4): 259–271.
22. Alberto D., Garello R. Corneal Sublayer Thickness Estimation Using High-Resolution FD-OCT [J]. *Journal of Biomedical Imaging*, 2013, 2013: 11–11.
23. Rattan S. A., Anwar D. S. A comparative analysis of corneal epithelial thickness profiles in patients with dry eye, keratoconus suspects, and healthy individuals [J]. *European Journal of Ophthalmology*, 2020, 30(6): 1506-1511.
24. Certainly! Below is the polished version of the provided content:Vega-Estrada, A., & Alió, J. L. "Characterization of the Posterior Corneal Surface in Keratoconus Based on the Degree of Visual Limitation" [J]. *Cornea*, 2019, 38(6): 730–736
25. Serrao S, Lombardo G, Calì C, et al. The Importance of Corneal Epithelial Thickness Mapping in Assessing Keratoconus [J]. Contact Lens and Anterior Eye, 2019, 42(6): 662-665.
26. Xu Z., Jiang J., Yang C., et al. *The diagnostic value of corneal epithelial and Bowman’s layer vertical thickness profiles using UHR-OCT for detecting subclinical keratoconus* [J]. *Scientific Reports*, 2016, 6(1): 31550.
27. Salman A., Mazzotta C., Kailani O., et al. *Diagnostic Accuracy of Corneal and Epithelial Thickness Map Parameters in Detecting Keratoconus and Suspected Keratoconus* [J]. *Journal of Ophthalmology*, 2023, Vol. 2023.

Figures

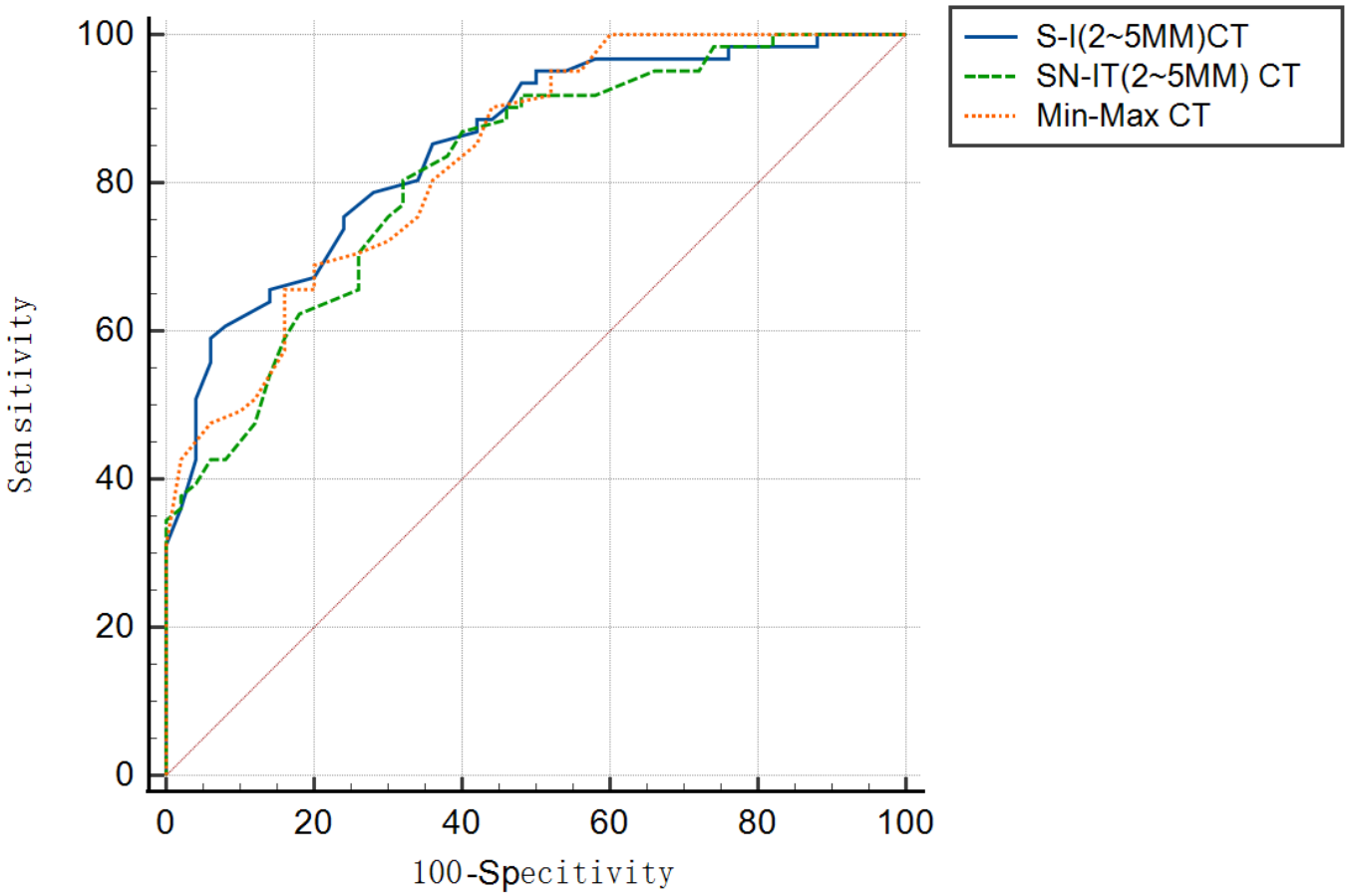


Figure 1

Comparative analysis of corneal thickness parameters under the optimal working characteristic curve for distinguishing suspected keratoconus from normal eyes. SN-IT (2-5mm) CT, the difference between the mean thickness of supranasal and infratemporal octants of the cornea (2 to 5 mm from the center); S-I (2-5mm) CT,the difference between the mean thickness of the inferior and superior octants of the cornea (2 to 5 mm from the center) , and Min-Max CT,the difference between the minimum and the maximum corneal thickness point

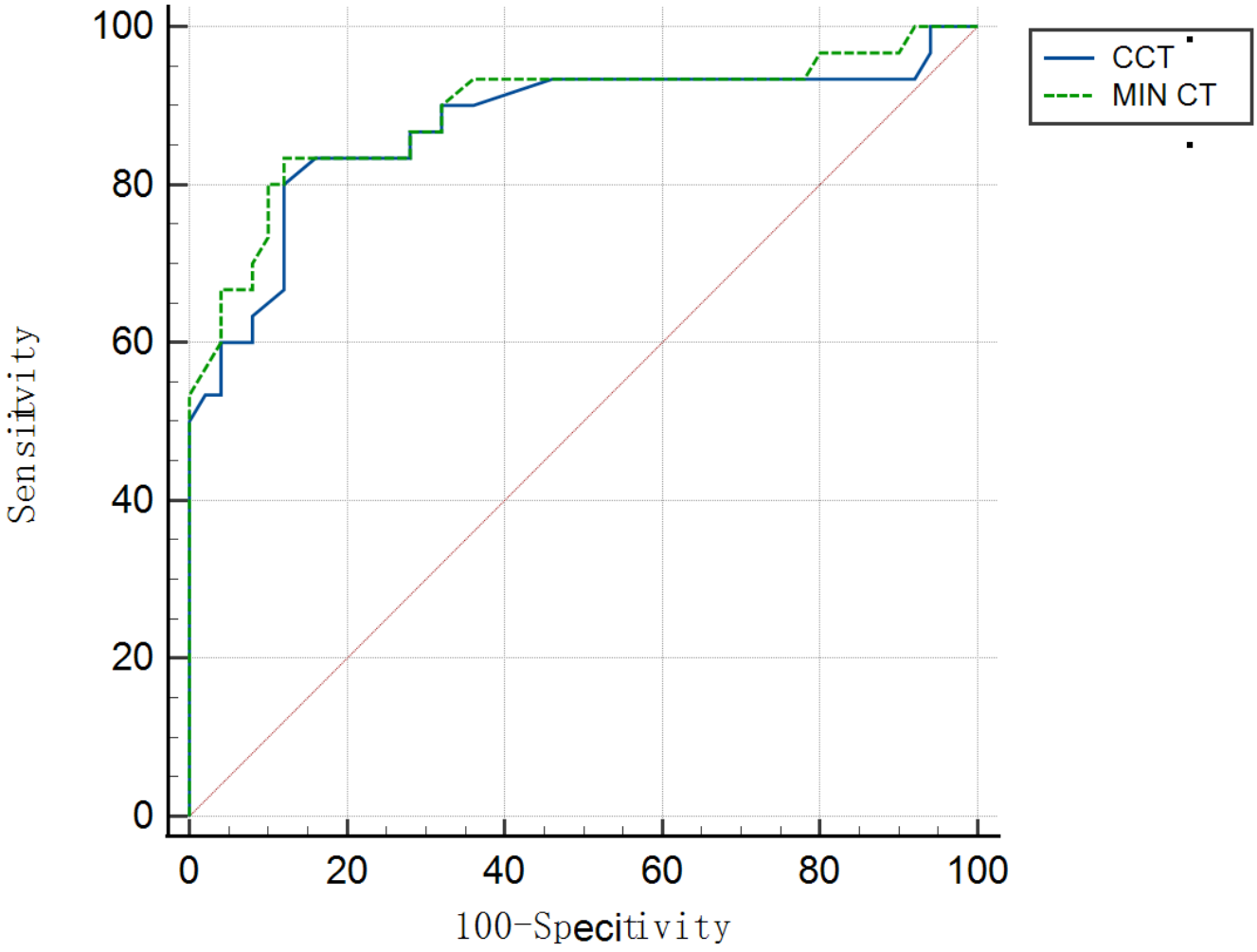


Figure 2

Comparative analysis of corneal thickness parameters under the optimal working characteristic curve for distinguishing subclinical keratoconus from normal eyes. CCT, central corneal thickness; MIN CT, minimum corneal thickness point

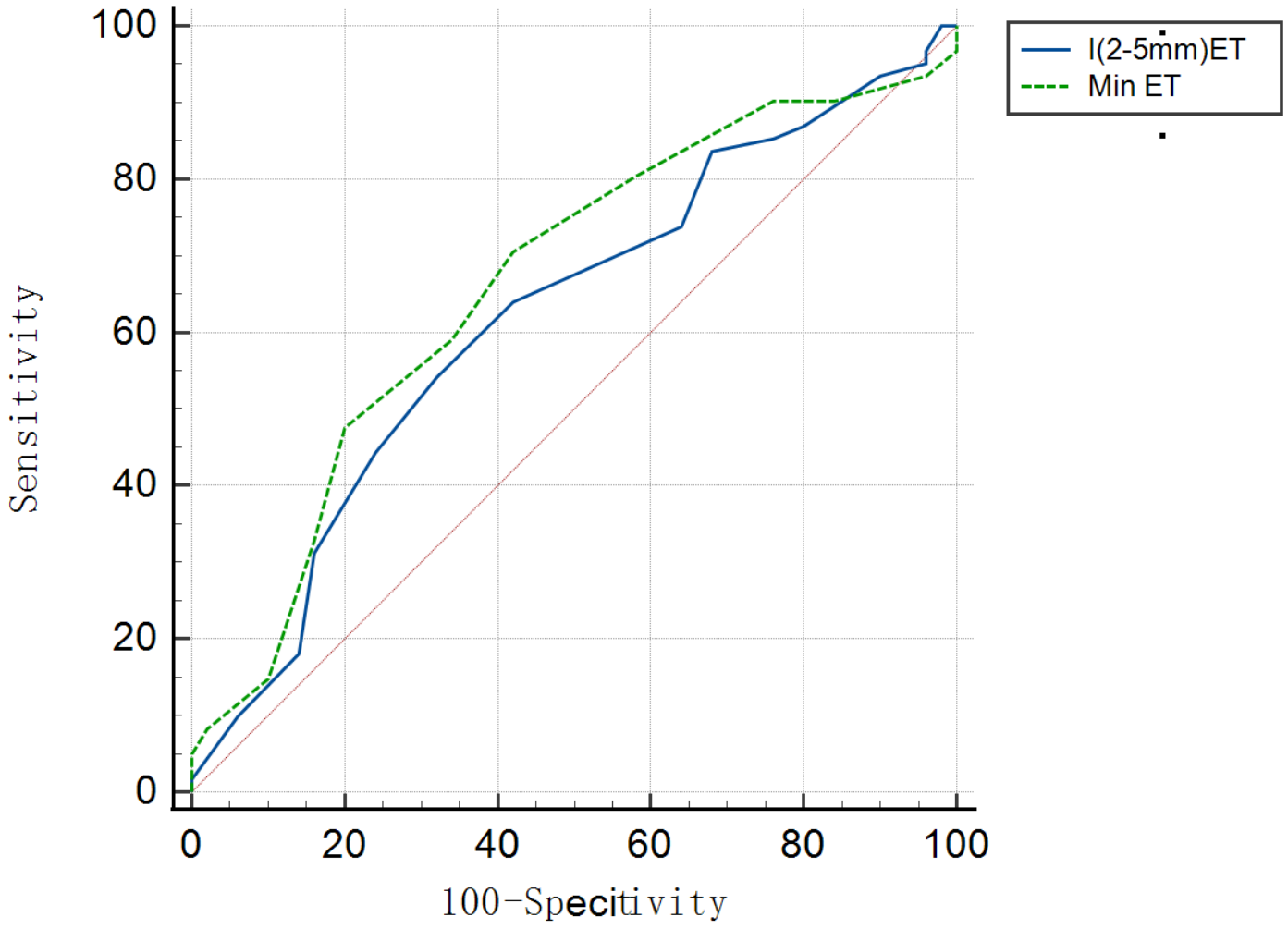


Figure 3

Comparative analysis of corneal epithelial thickness parameters in the optimal working characteristic curve region for distinguishing suspected keratoconus from normal eyes. I (2-5mm) ET,the mean of thickness values recorded in the inferior epithelium (2 to 5 mm from the center); Min ET, the minimum corneal epithelial thickness point

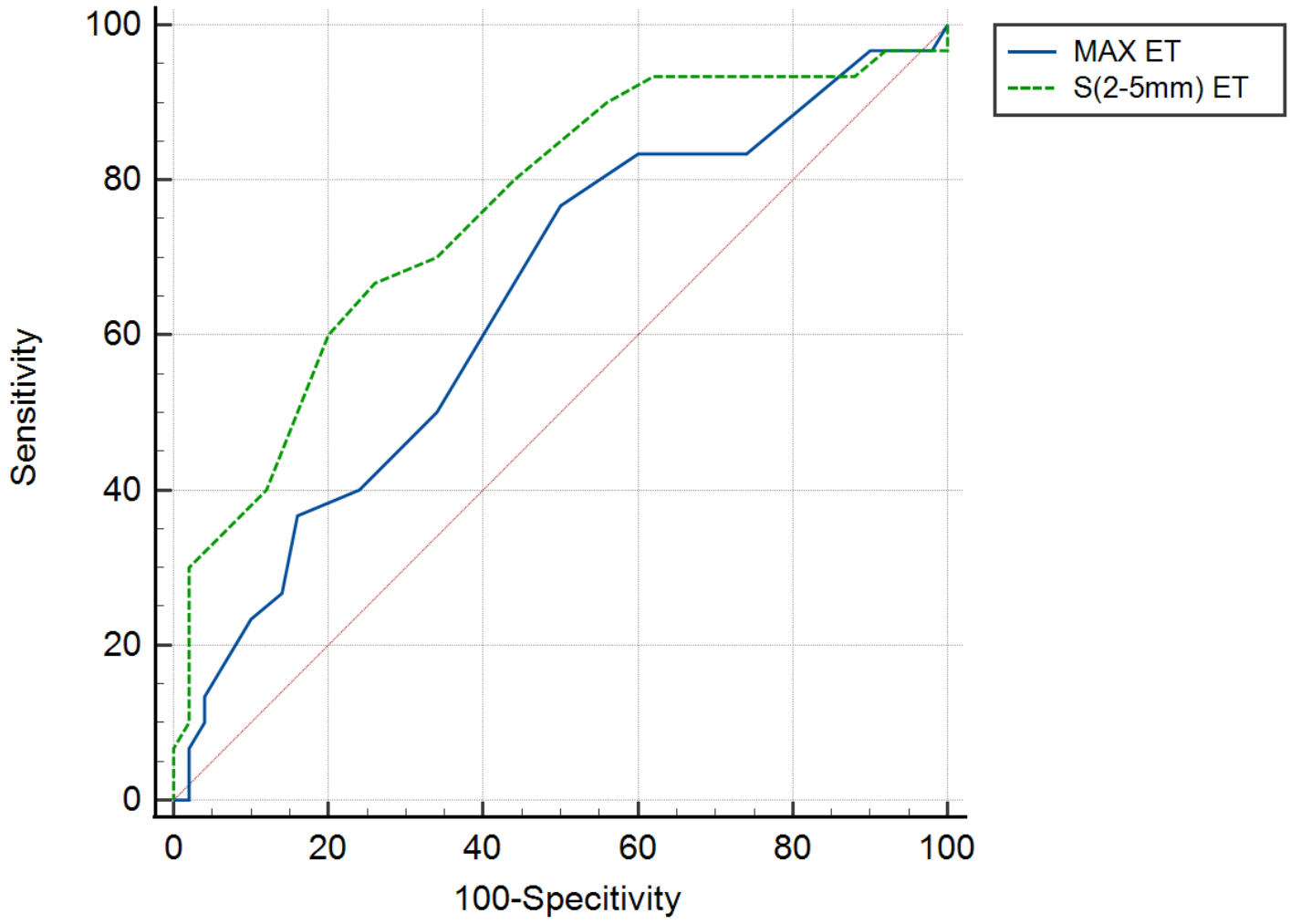


Figure 4

Comparative parameters of corneal epithelial thickness in the optimal region of the subject work characteristic curve for distinguishing subclinical keratoconus from normal eyes. S (2-5mm) ET, the mean of thickness values recorded in the superior epithelium (2 to 5 mm from the center);MAX ET, the maximum corneal epithelial thickness point

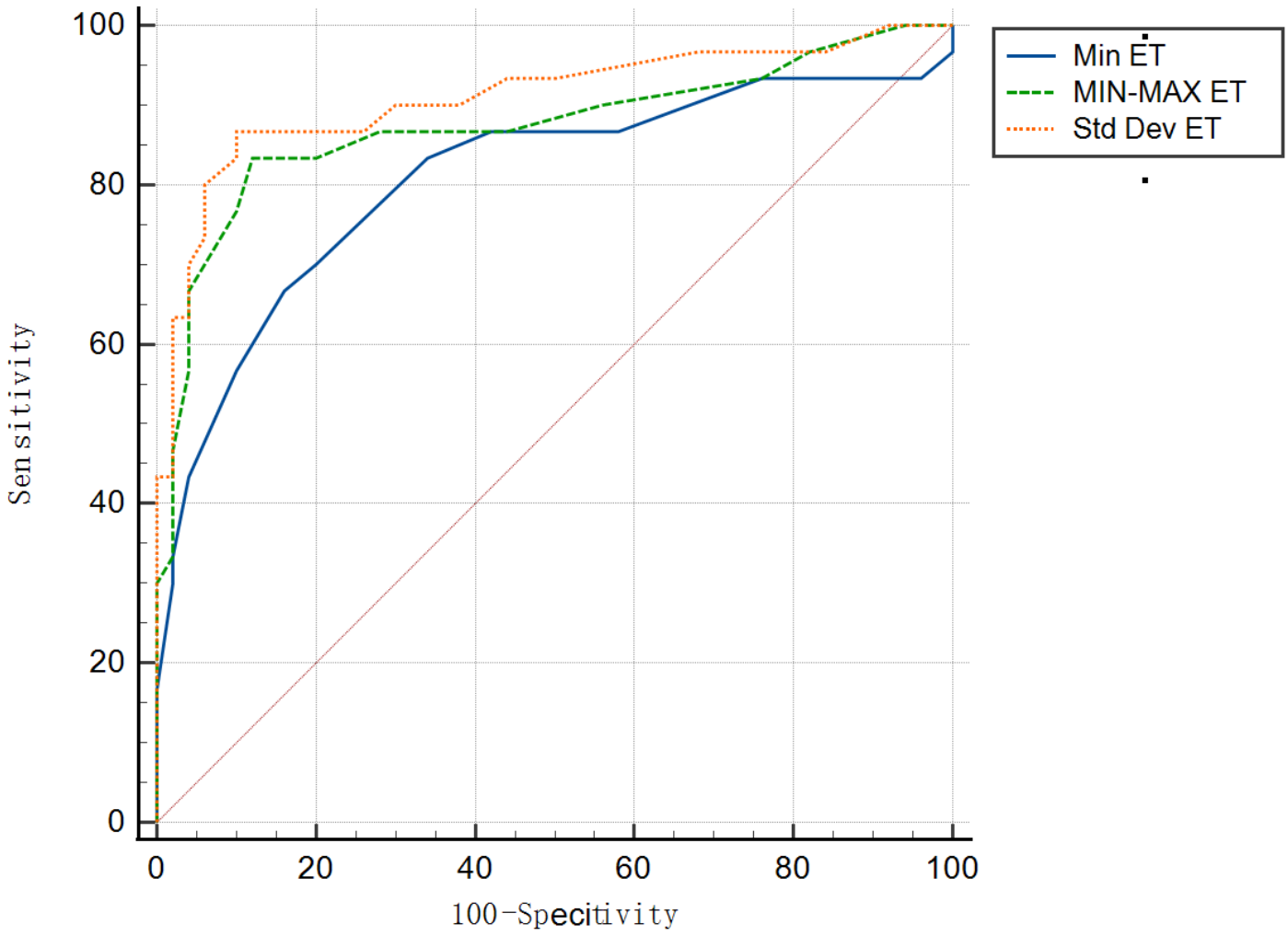


Figure 5

Comparative analysis of corneal epithelial thickness parameters under the optimal region of the subject's working characteristic curve for distinguishing keratoconus eyes from normal eyes. Min ET, the minimum corneal epithelial thickness point; MAX ET, the maximum corneal epithelial thickness point;MIN-MAX ET, the difference between the minimum and the maximum corneal epithelial thickness point; MSD ET, the standard deviation of all epithelial thicknesses mapping recorded in the central 5 mm of the cornea.