Figure S1 ROC and PR curves for the different methods in opacity density grading. (A) ROC curves and AUC values for the CCNN-Ensemble method and four comparison methods: WT-Ada, SIFT-Ada, LBP-Ada, and COTE-Ada. (B) PR curves for the CCNN-Ensemble method and the four comparative methods. ROC, receiver operating characteristic curve; AUC, area under the ROC curve; PR, precision-recall curve; CCNN-Ensemble, ensemble learning of cost-sensitive convolutional neural networks; Ada, adaptive boosting ensemble learning; WT, wavelet transformation; LBP, local binary pattern; SIFT, scale-invariant feature transform; COTE, color and texture features.
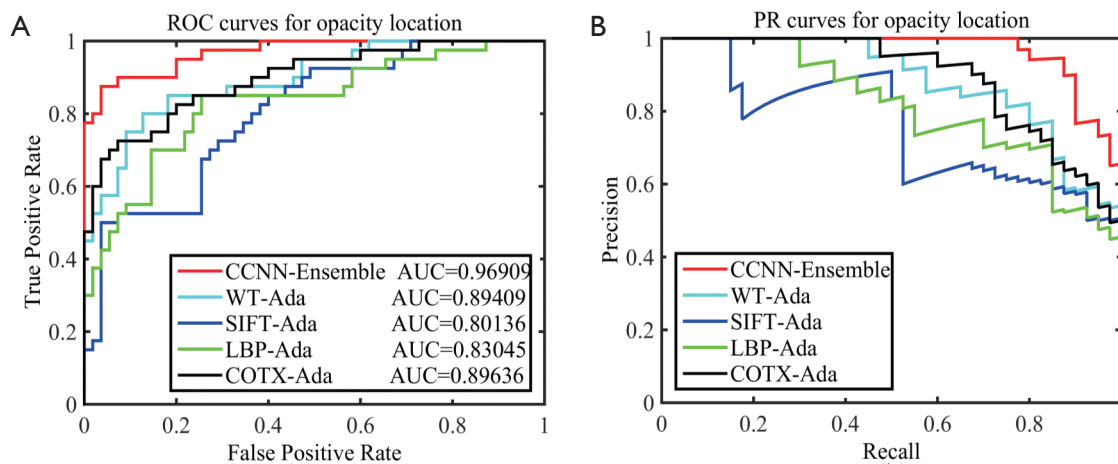

Figure S2 ROC and PR curves for the different methods in opacity location grading. (A) ROC curves and AUC values for the CCNN-Ensemble method and four comparison methods: WT-Ada, SIFT-Ada, LBP-Ada, and COTE-Ada. (B) PR curves for the CCNN-Ensemble method and the four comparison methods. ROC, receiver operating characteristic curve; AUC, area under the ROC curve; PR, precision-recall curve; CCNN-Ensemble, ensemble learning of cost-sensitive convolutional neural networks; Ada, adaptive boosting ensemble learning; WT, wavelet transformation; LBP, local binary pattern; SIFT, scale-invariant feature transform; COTE, color and texture features; WT-Ada, adaptive boosting ensemble learning with wavelet transformation feature.

Table S1 Performance comparison of CCNN-Ensemble with conventional features and Adaboost ensemble methods in the opacity density grading

Method	ACC (%)	SPE (%)	SEN (%)	F1_M (%)	G_M (%)	AUC (%)
WT	84.04 (3.28) [§]	89.62 (3.22)	77.14 (3.98)	81.20 (3.83)	83.13 (3.36)	90.05 (1.69)
WT- AdaBoost	83.83 (3.56)	86.92 (2.51)	80.00 (5.48)	81.50 (4.31)	83.37 (3.79)	90.33 (1.92)
LBP	74.47 (2.61)	81.54 (4.63)	65.71 (3.61)	69.70 (2.78)	73.14 (2.46)	81.38 (4.09)
LBP- AdaBoost	75.74 (4.41)	76.54 (6.58)	74.76 (6.43)	73.35 (4.54)	75.52 (4.34)	82.30 (4.17)
SIFT	74.47 (4.12)	69.62 (5.83)	80.48 (4.26)	73.83 (3.93)	74.79 (4.07)	83.73 (1.96)
SIFT- AdaBoost	66.38 (2.87)	46.92 (6.46)	90.48 (3.37)	70.66 (1.79)	64.99 (3.67)	83.91 (1.92)
COTX	84.26 (4.72)	86.54 (9.52)	81.43 (3.91)	82.38 (4.25)	83.78 (4.25)	89.78 (4.50)
COTX- AdaBoost	84.26 (2.95)	86.15 (4.17)	81.90 (4.64)	82.29 (3.31)	83.95 (3.01)	92.06 (2.74)
CCNN-Ensemble	*92.77 (1.39)*	*93.85 (1.61)*	*91.43 (2.71)*	*91.86 (1.62)*	*92.62 (1.47)*	*98.01 (0.85)*

[§], Mean (Standard Deviation). ACC, accuracy; SPE, specificity; SEN, sensitivity; F1_M, F1-measure; G_M, G-mean; AUC, area under the receiver operating characteristic curve; WT, wavelet transformation; LBP, local binary pattern; SIFT, scale-invariant feature transform; COTE, color and texture features; Adaboost, adaptive boosting ensemble learning; CCNN-Ensemble, ensemble learning of cost-sensitive convolutional neural networks.

Table S2 Performance comparison of CCNN-Ensemble with conventional features and Adaboost ensemble methods in the opacity location grading

Method	ACC (%)	SPE (%)	SEN (%)	F_M (%)	G_M (%)	AUC (%)
WT	81.06 (2.81) [§]	89.04 (2.34)	69.91 (5.46)	75.42 (3.85)	78.85 (3.29)	89.34 (2.69)
WT- AdaBoost	83.60 (3.53)	85.75 (3.82)	80.62 (6.42)	80.35 (4.38)	83.08 (3.79)	90.56 (3.41)
LBP	75.52 (4.67)	80.27 (4.85)	68.88 (10.4)	69.90 (6.35)	74.15 (5.35)	81.70 (5.64)
LBP- AdaBoost	76.58 (3.73)	73.34 (5.21)	81.10 (9.03)	74.16 (4.56)	76.94 (3.92)	82.81 (6.18)
SIFT	77.47 (4.44)	76.30 (9.90)	79.05 (8.06)	74.56 (4.09)	77.32 (4.14)	85.46 (3.47)
SIFT- AdaBoost	68.72 (1.31)	55.11 (5.66)	87.76 (5.84)	70.03 (1.14)	69.34 (1.83)	85.08 (3.40)
COTX	81.05 (5.04)	90.12 (6.46)	68.33 (13.2)	74.52 (8.88)	78.00 (7.37)	90.18 (3.58)
COTX- AdaBoost	85.52 (5.79)	91.21 (5.00)	77.58 (8.07)	81.68 (7.32)	84.07 (6.16)	91.62 (3.48)
CCNN-Ensemble	*92.76 (2.06)*	*95.25 (2.08)*	*89.29 (3.30)*	*91.14 (2.53)*	*92.21 (2.19)*	*97.29 (1.36)*

[§], Mean (Standard Deviation). ACC, accuracy; SPE, specificity; SEN, sensitivity; F1_M, F1-measure; G_M, G-mean; AUC, area under the receiver operating characteristic curve; WT, wavelet transformation; LBP, local binary pattern; SIFT, scale-invariant feature transform; COTE, color and texture features; Adaboost, adaptive boosting ensemble learning; CCNN-Ensemble, ensemble learning of cost-sensitive convolutional neural networks.

Table S3 Performance comparison of CCNN-Ensemble with single-classifier CNNs and conventional ensemble learning methods based on CNNs in opacity density grading

Method	ACC (%)	SPE (%)	SEN (%)	F1_M (%)	G_M (%)	AUC (%)
AlexNet	88.09 (2.65) [§]	88.85 (3.16)	87.14 (4.64)	86.34 (3.71)	87.95 (2.76)	93.16 (2.32)
GoogLeNet	88.94 (2.68)	89.62 (2.92)	88.10 (4.45)	87.65 (2.73)	88.80 (2.58)	94.55 (2.04)
ResNet50	89.57 (2.75)	90.38 (2.36)	88.57 (4.88)	88.32 (2.28)	89.44 (2.95)	95.46 (1.92)
Ave-Ensemble	90.43 (1.86)	91.15 (2.01)	89.26 (2.80)	89.26 (2.12)	90.29 (2.42)	96.41 (1.64)
Ave-BRS-3ResNet	90.00 (2.33)	90.77 (2.24)	89.05 (3.26)	88.80 (2.30)	89.86 (2.56)	96.23 (1.83)
CCNN-Ensemble	92.77 (1.39)	93.85 (1.61)	91.43 (2.71)	91.86 (1.62)	92.62 (1.47)	98.01 (0.85)

[§], Mean (Standard Deviation). ACC, accuracy; SPE, specificity; SEN, sensitivity; F1_M, F1-measure; G_M, G-mean; AUC, area under the receiver operating characteristic curve; Ave-Ensemble, ensemble learning of three different CNNs (AlexNet, GoogLeNet and ResNet50) with an averaging technique; Ave-BRS-3ResNet, ensemble learning of three ResNet50 architectures with batch random selection and averaging techniques; CCNN-Ensemble, ensemble learning of cost-sensitive convolutional neural networks.

Table S4 Performance comparison of CCNN-Ensemble with single-classifier CNNs and conventional ensemble learning methods based on CNNs in opacity location grading

Method	ACC (%)	SPE (%)	SEN (%)	F1_M (%)	G_M (%)	AUC (%)
AlexNet	88.30 (2.78)	90.88 (4.37)	84.71 (3.55)	85.81 (3.05)	87.71 (2.57)	90.71 (3.23)
GoogLeNet	88.72 (2.54)	91.25 (3.28)	85.21 (3.27)	86.30 (3.72)	88.15 (2.38)	92.24 (3.02)
ResNet50	89.58 (2.02)	91.61 (3.12)	86.76 (2.89)	87.43 (2.29)	89.11 (2.01)	93.70 (2.63)
Ave-Ensemble	90.64 (1.45)	92.70 (1.98)	87.77 (2.01)	88.66 (1.14)	90.19 (1.24)	94.83 (1.64)
Ave-BRS-3ResNet	90.21 (1.68)	92.34 (2.21)	87.26 (2.47)	88.14 (1.34)	89.74 (1.52)	94.05 (1.95)
CCNN-Ensemble	92.76 (2.06)	95.25 (2.08)	89.29 (3.30)	91.14 (2.53)	92.21 (2.19)	97.29 (1.36)

[§], Mean (Standard Deviation). ACC, accuracy; SPE, specificity; SEN, sensitivity; F1_M, F1-measure; G_M, G-mean; AUC, area under the receiver operating characteristic curve; Ave-Ensemble, ensemble learning of three different CNNs (AlexNet, GoogLeNet and ResNet50) with averaging technique; Ave-BRS-3ResNet, ensemble learning of three ResNet50 architectures with batch random selection and averaging techniques; CCNN-Ensemble, ensemble learning of cost-sensitive convolutional neural networks.