· 临床研究 ·

多光谱眼底分层成像仪获取白内障眼眼底图像的可行性研究

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【摘要】 **目的**　探讨多光谱眼底分层成像仪(RHA)在白内障眼中获取可用于观察分析的眼底图像的可行性。**方法**　采用横断面研究设计,纳入 2016 年 12 月至 2017 年 1 月于上海交通大学附属第一人民医院接受手术的白内障患者 41 例 45 眼。扩瞳后行晶状体混浊程度分级以及 RHA 眼底成像检查。按晶状体混浊程度分为 4 个组:皮质混浊组 18 眼,核性混浊组 21 眼,后囊下混浊组 2 眼和混合型组 4 眼。采用 RHA2020 全层扫描模式获取眼底图像,对眼底图像清晰程度进行评价,并比较皮质混浊组及核性混浊组眼底图像清晰度评分。**结果**　45 眼中晶状体混浊度最轻的 1 眼分级为 C0N2P0,最重的 2 眼分级分别为 C2N5P2 和 C4N2P4。晶状体核混浊 4 级、皮质混浊 3 级或后囊下混浊 3 级明显降低 RHA 眼底图片的清晰度,尤其是红绿光组合图(620 nm+550 nm)的清晰度降低最明显。在光谱 580 nm 和 590 nm 处可观察到皮质混浊组视盘及视网膜血管,清晰程度评分分别为 2.0(1.0,3.0)和 2.0(2.0,3.0);在光谱 810 nm 处可观察到视网膜血管、脉络膜血管以及色素分布,清晰程度评分为 2.0(2.0,3.0),显著低于红绿光组合图的 3.0(2.0,3.0),差异有统计学意义($P<0.05$)。核性混浊组中,核混浊 3 级时 RHA 眼底图像仍清晰;核混浊 4 级时 RHA 眼底图像清晰度明显下降,在光谱 580 nm 和 590 nm 处偶可见视网膜血管,其清晰程度评分分别为 1.0(1.0,3.0)和 2.0(1.0,3.0);在光谱 810 nm 和 850 nm 处可观察视网膜血管、脉络膜血管以及色素分布,其清晰程度评分为 2.0(1.0,3.0),显著低于红绿光组合图的 3.0(1.5,3.0),差异有统计学意义($P<0.05$)。在后囊下混浊组中,光谱 580 nm 处可观察视网膜血管,光谱 810 nm 和 850 nm 处可观察视网膜血管、脉络膜血管以及色素分布。混合型白内障组中 850 nm 处可观察到视网膜血管走行,血管反光不可见,脉络膜血管区域性可见。**结论**　除重度白内障外,RHA 中 580、590、810 和 850 nm 光谱成像可获取白内障患者的眼底图像,有助于及时发现白内障术前眼底疾病以及评估预后。

【关键词】　多光谱眼底分层成像;白内障;屈光间质混浊;眼底成像
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Feasibility of fundus imaging in cataractous eyes by Retinal Health Assessment System

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[Abstract] **Objective**　To study the ability of the Retinal Health Assessment (RHA) system to obtain fundus images in patients with different types and degrees of cataracts.　**Methods**　A cross-sectional study was performed. Forty-five eyes of 41 patients with cataract were enrolled in First People's Hospital, Shanghai Jiaotong University from December 2016 to January 2017. Lens opacity grading and RHA fundus imaging were performed after pupil dilation. Forty-five eyes were divided into 4 groups according to the degree of lens opacity: cortical cataract group 18 eyes, nucleus cataract group 21 eyes, posterior subcapsular cataract group 2 eyes, hybrid cataract group 4 eyes. Fundus images were obtained by FullSpectrum mode of RHA2020, and the clearness of fundus images was evaluated. Scores of fundus images clarity were compared between the cortical cataract group and nucleus cataract group. This study was approved by the Ethics Committee of First People's Hospital, Shanghai Jiaotong University. Written informed consent was obtained from each patient prior to any medical examination. **Results** In all 45 eyes, the phacoscotasmus classification ranged from mildest (C0N2P0, 1 eye) to very serious (C2N5P2 and C4N2P4, 2 eyes). The grade Ⅳ nuclear opacity, grade Ⅲ cortical opacity, and grade Ⅲ posterior subcapsular opacity reduced the quality of RHA images significantly, especially for images with red and green light. In cortical cataract group, images showed peripapillary vessels and retinal vessels at 580 nm and 590 nm, while retinal and choroidal vessels, as well as choroidal pigmentation, were visible at 810 nm. The clarity scores at 580, 590 and 810 nm were 2.0 (1.0, 3.0), 2.0 (2.0, 3.0) and 2.0 (2.0, 3.0), which were lower than that with red and green light (620 nm + 550 nm) (3.0[2.0, 3.0]), with statistically significant differences (all at $P<0.05$). In nucleus cataract group, the quality of fundus images from the eyes with grade Ⅲ nucleus cataracts was good, the image quality decreased when the nucleus opacity was grade Ⅳ, retinal vessels were occasionally observed at 580 nm and 590 nm. Additionally, retinal and choroidal vessels and choroidal pigment were visible at 810 nm and 850 nm. The clarity scores at 580, 590, 810 and 850 nm were 1.0 (1.0, 3.0), 2.0 (1.0, 3.0) and 2.0 (1.0, 3.0), which were lower than that with red and green light (620 nm + 550 nm) (3.0[1.5, 3.0]), with statistically significant differences (all at $P<0.05$). In posterior subcapsular cataract group, the retinal vessels were visible at 580 nm, meanwhile retinal and choroidal vessels and choroidal pigment could be observed at 810 nm and 850 nm. In hybrid cataract group, running lines of retinal vessels could be seen at 850 nm, while the central reflection was absent. Focal choroidal vessels were observed. **Conclusions** Except for severe cases, RHA system can produce good quality fundus images in cataract eyes at 580, 590, 810 and 850 nm, facilitating the evaluation of fundus disease before surgery and prediction of visual outcomes after surgery.

[**Key words**] Multispectral imaging; Cataract; Optical media opacity; Fundus imaging

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精确的眼底评估对各类眼病的诊疗具有重要意义。目前临床上较常用的眼底检查技术包括眼底检眼镜检查、眼底照相、光相干断层扫描(optical coherence tomography, OCT)、荧光素眼底血管造影(fundus fluorescein angiography, FFA)和吲哚青绿血管造影(indocyanine green angiography, ICGA)等。眼底检眼镜检查及眼底照相可用于视网膜形态特征的观察[1-2],其检查结果的准确性主要取决于检查者的经验和能力,且无法用于客观随访。传统眼底照相采用480~600 nm 波长光获取浅层视网膜图像,彩色眼底照相则采用 532 nm 波长绿光(获取视网膜色素上皮以内各层图像)和 633 nm 波长红光(穿透视网膜色素上皮层到达脉络膜)成像[3]。OCT 利用眼部不同组织对 830 nm 近红外光的反射原理形成矢状面图像[4],能清晰地显示视网膜及脉络膜的组织学形态[5-6]。ICGA 采用 488 nm/810 nm 光对脉络膜成像,为有创检查技术[4],主要显示眼底血管结构[7-8]。这些客观检查技术虽然可从不同层面检查眼底疾病,但在屈光间质混浊眼中难以获得清晰的眼底图像。近 2 年投入临床应用的多光谱眼底成像仪(Retinal Health Assessment, RHA)利用多光谱眼底分层成像系统(Multi Spectral Fundus Imaging System, MSI)显示眼底形态,操作简便,且为非侵入性成像技术。RHA 采用广谱光(550~850 nm)间隔 10~50 nm 连续获取 10 张包括视网膜各层和脉络膜的冠状面图像[9-10],内设多种成像模式以达到多层次、多种疾病诊断的目的,如多光谱红绿组合成像(550 nm+620 nm)可模拟彩色眼底照相,黄琥珀光组合多光谱视网膜血管成像(580 nm+590 nm)可模拟 FFA,红外光组合多光谱脉络膜血管成像(760 nm+810 nm)可模拟 ICGA,多光谱自发荧光成像可模拟普通自发荧光成像[11]。白内障是常见的屈光间质混浊眼病,白内障术前的眼底结构和功能评估对于白内障手术预后效果判断至关重要。然而,RHA 是否能在屈光间质混浊眼获取可用于分析的眼底图像,目前尚不明确。本研究中采用 RHA 获取不同类型和不同程度白内障患者的眼底图像,探讨 RHA 在白内障眼中获取可用于分析的眼底图像的可行性。

1 资料与方法

1.1 一般资料

采用横断面研究设计,纳入 2016 年 12 月至 2017 年 1 月于上海交通大学附属第一人民医院拟行手术治疗的白内障患者 41 例 45 眼,其中男 15 例 16 眼,女26例29眼;年龄43~91岁,平均(69.15±10.65)岁;

术前矫正视力光感~0.6，术前眼轴长度为 21.40~26.84 mm，平均(23.98±1.52) mm。纳入标准：(1)年龄相关性白内障患者；(2)年龄≥40 岁。排除标准：(1)有角膜病、玻璃体积血等其他眼屈光间质混浊疾病者；(2)合并青光眼、葡萄膜炎、糖尿病视网膜病变、黄斑病变等疾病者；(3)有眼部手术史者；(4)有眼部外伤史者；(5)有糖尿病等全身代谢性疾病者；(6)有明确的眼部辐射接触史者；(7)眼轴长度≥27.00 mm 的高度近视者[12-13]。同期纳入健康志愿者 3 人 6 眼作为正常对照组，其中男 2 人，女 1 人；年龄 24~40 岁；矫正视力均为 1.0，屈光度为-2.00~4.00 D。本研究项目由上海交通大学附属第一人民医院伦理委员会批准(批文号：2013KY023)，所有纳入患者均签署知情同意书。

1.2 方法

1.2.1 晶状体混浊分级 所有患者术前均接受最佳矫正视力、裂隙灯生物显微镜、检眼镜、眼部 OCT 和 B 型超声检查。所有患者复方托吡卡胺滴眼液扩瞳至瞳孔直径≥6 mm，由 2 名医师分别在裂隙灯生物显微镜下采用 Chylack 晶状体混浊分类系统Ⅲ(LOCS Ⅲ)[14]进行晶状体混浊程度分级。各型白内障 LOCS Ⅲ标准：(1)皮质混浊性白内障 核混浊、核颜色级别(N)≤2，皮质混浊级别(C)>2，后囊膜混浊级别(P)≤2。(2)核性混浊白内障 核混浊、核颜色级别(N)>2，皮质混浊级别(C)≤2，后囊膜混浊级别(P)≤2。(3)后囊下混浊白内障 核混浊、核颜色级别(N)≤2，皮质混浊级别(C)≤2，后囊膜混浊级别(P)>3。(4)混合型白内障 核混浊、核颜色级别(N)>2，皮质混浊级别(C)>2，后囊膜混浊级别(P)>2(满足 2 项或以上)[15]。按晶状体混浊程度分为 4 个组：皮质混浊组 18 眼，核性混浊组 21 眼，后囊下混浊组 2 眼和混合型组 4 眼。若结果不统一，则由第 3 位临床经验丰富的医师进行分级。

1.2.2 RHA 眼底成像检查 晶状体混浊分级完成后，在瞳孔扩大状态下由 1 名具备熟练 RHA 操作经验的眼科医生，采用 RHA2020 (RHA mutlti-spectral Digital Ophthalmoscope, Annidis, Canada, 2014, SN 04021650155)全层扫描模式获取眼底图像。全层扫描模式 1 次可获取 14 帧图片，其中在 550、580、590、620、660、690、740、760、780、810 和 850 nm 处成像各 1 帧。另有 3 帧组合图：多光谱红绿组合成像(550 nm+620 nm，可模拟彩色眼底照相)，黄琥珀光组合多光谱视网膜血管成像(580 nm+590 nm，可模拟 FFA)和多光谱脉络膜血管成像(760 nm+810 nm，可模拟 ICGA)。另由一位临床经验丰富的主任医师根据表 1 对眼底图像进行清晰度评分。

表 1 RHA 获取眼底图像清晰程度评价标准

Table 1 Evaluation criteria for the clarity of the fundus images obtained through RHA

眼底图像清晰程度(分值)	550、580、590 和 620 nm 处成像	660、690 和 740 nm 处成像	760、780 和 810 nm 处成像
清晰(1 分)	视网膜血管、视盘血管清晰可见，动静脉反光可见	脉络膜血管清晰可见	脉络膜色素清晰可见
欠清(2 分)	视网膜血管、视盘血管走行可见，血管壁不清，动静脉反光模糊	脉络膜血管部分可见	脉络膜色素部分可见
模糊(3 分)	视网膜血管仅隐约可见走行，视盘血管不可见，动静脉反光不可见	少量脉络膜血管或不可见	脉络膜色素不可见
不可见(4 分)	眼底结构完全不可见	眼底结构完全不可见	眼底结构完全不可见

注：RHA：多光谱眼底分层成像仪

Note：RHA：Retinal Health Assessment

1.3 统计学方法

采用 SPSS 20.0 统计学软件(美国 IBM 公司)进行统计分析。本研究中 RHA 眼底成像清晰程度评分的数据经 Shapiro-Wilk 检验不符合正态分布，以 $M(Q_1, Q_3)$表示。各个谱段与红绿光组合 RHA 图像清晰程度评分的差异比较采用 Wilcoxon 秩和检验。$P<0.05$ 为差异有统计学意义。

2 结果

2.1 白内障患者晶状体混浊分级情况

45 眼中皮质混浊性白内障 18 眼，核性混浊白内障 21 眼，后囊下混浊白内障 2 眼，混合型白内障 4 眼。晶状体混浊度最轻的 1 眼分级为 C0N2P0，最重的 2 眼分级分别为 C2N5P2 和 C4N2P4。

2.2 正常对照组 RHA 眼底图像分析

RHA 图像显示范围约为后极部 42°。在多光谱 550~590 nm 成像中，清晰观察到视盘及视杯；视网膜动静脉管径比约为 2∶3，走行自然，分支均匀、清晰，部分图像中管径中部伴浅白色反光；黄斑部呈浅黑色或灰色，中心凹处呈浅白色点状反光；脉络膜血管尚未透见。红绿光组合(620 nm+550 nm)眼底图像可见视盘及血管，视网膜血管；黄琥珀光组合(580 nm+590 nm)光谱视网膜血管图可见视网膜血管轮廓，模拟 FFA。在多光

谱 620~850 nm 成像中,脉络膜血管随着 MSI 波长的加大逐渐清晰,同时眼底背景逐渐被斑驳的脉络膜血管条纹所取代,红外光组合(760 nm+810 nm)光谱脉络膜血管图可见脉络膜血管轮廓,模拟 ICGA(图 1)。

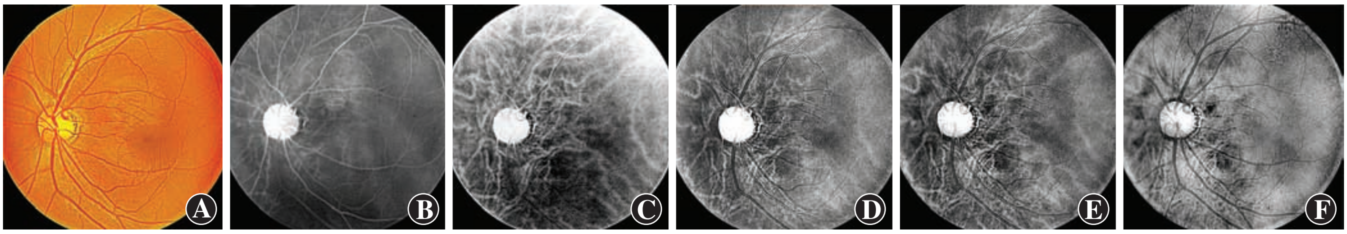

图 1　1 例正常对照 RHA 眼底表现　男,24 岁,眼轴长度 24.56 mm,屈光度为-3.00 D　A:红绿光组合(620 nm+550 nm)眼底图像中视盘及血管、视网膜血管均清晰可见　B:黄琥珀光组合(580 nm+590 nm)光谱视网膜血管图中可清晰观察到视网膜血管轮廓,模拟 FFA　C:红外光组合(760 nm+810 nm)光谱脉络膜血管图中可清晰观察到脉络膜血管轮廓,模拟眼底 ICGA　D:光谱 660 nm 眼底像中视网膜血管清晰,可辨认出除黄斑区以外的脉络膜血管,视盘血管不可见　E:光谱 740 nm 眼底图像中黄斑区脉络膜血管出现　F:光谱 850 nm 眼底图像中脉络膜血管欠清晰,可见脉络膜色素

Figure 1　RHA fundus image of one normal control　Male, 24 years old, left eye, axial length was 24.56 mm, diopter was −3.00 D　A: Fundus imaging of the red and green light combination (620 nm + 550 nm) the optic nerve head and peripapillary blood vessels, as well as retinal blood vessels were clearly visible　B: Images of retinal blood vessels with yellow succinate light combination (580 nm + 590 nm) profile of retinal blood vessels were clearly visible, simulating FFA　C: Image of choroid blood vessel imaged with the infrared light combination (760 nm+810 nm) profiles of choroid blood vessels were clearly visible, simulating ICGA of the fundus　D: Fundus imaging with 660 nm of light retinal blood vessels were clearly seen; choroid blood vessels were distinguishable, in the macular area; the optic nerve head and peripapillary vessels were invisible　E: Fundus imaging with 740 nm of light choroid blood vessels in the macular area were visible　F: Fundus imaging with 850 nm of light: choroid blood vessels were not clearly seen, while the choroid pigment was visible

2.3　皮质混浊性白内障组 RHA 眼底分析

在皮质混浊性白内障组中 RHA 眼底成像清晰度下降,红绿光组合眼底像模糊,其评分为 3.00(2.00,3.00),视网膜血管、视盘血管及脉络膜血管清晰度明显下降;光谱 580 nm 和 590 nm 处评分分别为 2.00(1.00,3.00)和 2.00(2.00,3.00),可观察到视盘及视网膜血管;光谱 810 nm 处评分为 2.00(2.00,3.00),可观察到视网膜血管、脉络膜血管以及色素分布,清晰程度评分显著低于红绿光组合眼底像,差异有统计学意义($P<0.05$)(表 2),即光谱 580、590 和 810 nm 处眼底成像清晰度高于红绿光组合眼底像。C4N2P2 患者红绿光组合图像中仅视盘和后极部部分中央静脉模糊可见,光谱 590 nm、580 nm 图像中视网膜血管走行自然,分支均匀,光谱 810 nm 图像中视网膜血管模糊,视盘下方透见脉络膜血管,余象限脉络膜血管隐蔽,并可见脉络膜色素分布(图 2)。

2.4　核性混浊性白内障组 RHA 眼底图像分析

在核性混浊白内障组中光谱 580 nm 和 590 nm 处可观察到视盘及视网膜血管,分值为 1.0(1.0,3.0)和 2.0(1.0,3.0),光谱 810 nm 和 850 nm 处可观察到视网膜血管、脉络膜血管以及色素分布,分值为 2.0(1.0,3.0)和 2.0(1.0,3.0),低于红绿光组合眼底像的[3.0(1.5,3.0)],差异均有统计学意义(均 $P<0.05$)(表 2),即光谱 580、590、810 和 850 nm 处眼底成像清晰度高于红绿光组合眼底像。核混浊 3 级时,RHA 眼底成像仍清晰(图 3),与正常对照组清晰度类似。核混浊 4 级时 RHA 眼底像清晰度明显下降,红绿光组合眼底像模糊,光谱 580 nm 及 590 nm 处偶可见视网膜血管,810 nm 处可助观察视网膜血管、脉络膜血管以及色素分布。图 4 为 C0N4P0 核性白内障患者 RHA 眼底成像图,红绿光组合眼底结构模糊,眼底结构完全不可见,红外波段(760、780、810 和 850 nm)可见视盘血管走行,视盘下方脉络膜血管模糊及少量色素分布。

表 2　组内各个谱段和红绿光组合 RHA 眼底成像清晰程度评分比较[$M(Q_1,Q_3)$]

Table 2　Comparison of RHA fundus imaging clarity scores under different spectral conditions[$M(Q_1,Q_3)$]

谱段	眼底图像清晰度评分	
	皮质混浊组($n=18$)	核性混浊组($n=21$)
红绿光组合(620 nm+550 nm)	3.00(2.00,3.00)	3.00(1.50,3.00)
绿色(550 nm)	3.00(2.00,4.00)	2.00(1.00,4.00)
黄色(580 nm)	2.00(1.00,3.00)[a]	1.00(1.00,3.00)[a]
琥珀色(590 nm)	2.00(2.00,3.00)[a]	2.00(1.00,3.00)[a]
红色(620 nm)	2.00(2.00,3.00)[a]	2.00(1.00,3.00)[a]
红色 2(660 nm)	2.50(2.00,3.25)	2.00(1.00,3.00)
红色 3(690 nm)	2.00(2.00,3.00)	2.00(1.00,3.00)[a]
红色 4(740 nm)	2.00(2.00,3.00)[a]	2.00(1.00,3.00)[a]
近红外 3(760 nm)	2.00(2.00,3.00)[a]	2.00(1.00,3.00)[a]
近红外(780 nm)	2.00(2.00,3.00)[a]	2.00(1.00,3.00)[a]
近红外 2(810 nm)	2.00(2.00,3.00)[a]	2.00(1.00,3.00)[a]
近红外 4(850 nm)	2.00(2.00,2.25)[a]	2.00(1.00,3.00)[a]
黄琥珀光组合(580 nm+590 nm)	2.50(2.00,3.00)	2.00(1.00,3.00)[a]
红外光组合(760 nm+810 nm)	2.00(2.00,3.00)	2.00(2.00,3.00)

注:与红绿光组合眼底图像清晰度评分比较,[a]$P<0.05$(Wilcoxon 秩和检验)

Note: Compared to the clarity of images with red and green light, [a]$P<0.05$ (Wilcoxon rank sum test)

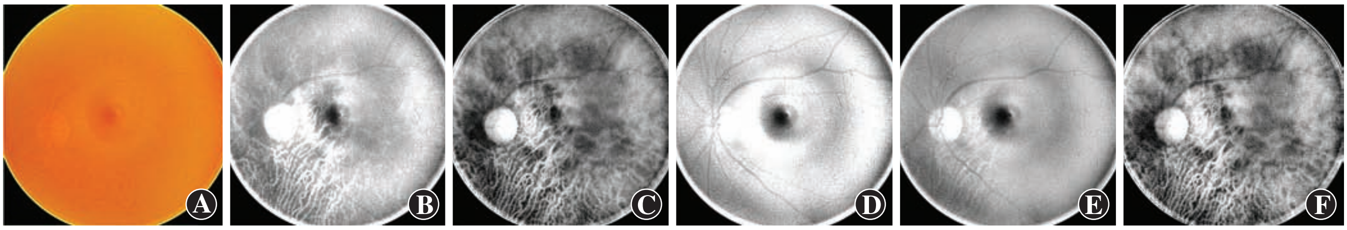

图 2　1 例 C4N2P2 皮质性白内障 RHA 眼底表现　女,65 岁,左眼,眼轴长度为 22.37 mm,屈光度为 -3.00 D　A:红绿光组合(620 nm+550 nm)眼底图像中视盘模糊可见,血管及黄斑区不可见　B:光谱 660 nm 眼底图像中颞上及颞下视网膜静脉主干模糊可见,黄斑区和(鼻下方象限除外)脉络膜血管模糊　C:光谱 760 nm 眼底图像中鼻下象限脉络膜血管清晰,余象限模糊　D:光谱 580 nm 眼底图像中黄斑区见伪迹,余视网膜血管走行清晰,反光不可见　E:光谱 590 nm 眼底图像中黄斑区见伪迹,视盘血管不可见,视网膜血管走行欠清晰,视盘下方少量脉络膜血管透见　F:光谱 810 nm 眼底图像中视网膜血管欠清晰,视盘下方脉络膜血管透见,可见脉络膜色素分布

Figure 2　RHA fundus image of C4N2P2 cortex cataract　Female, 65 years old, left eye, axial length was 22.37 mm, diopter was -3.00 D　A: Fundus imaging of the red and green light combination (620 nm+550 nm)　only the papilla of optic nerve was obscurely visible, while the blood vessels and macular area were invisible　B: Fundus imaging at 660 nm　the retinal vein trunk above and below the temporal region was obscurely visible, while the choroid blood vessels, except for the macular area and under nasal area, were obscure　C: Fundus imaging at 760 nm　choroid blood vessels under a nasal quadrant was clear, while the remaining quadrants were obscure　D: Fundus imaging at 580 nm　stimulus artifacts can be visible in the macular area, the resting retinal blood vessels have a clear running line, and the reflection was invisible　E: Fundus imaging at 590 nm　stimulus artifact can be visible in the macular area, blood vessels of the papilla of the optic nerve were invisible, the running lines of the retinal blood vessels were less clear, and a small number of choroid blood vessels below the optic disk were visible　F: Fundus imaging at 810 nm retinal blood vessels were less clear, choroid blood vessels below the optic disk were visible, and choroid pigment distribution was visible

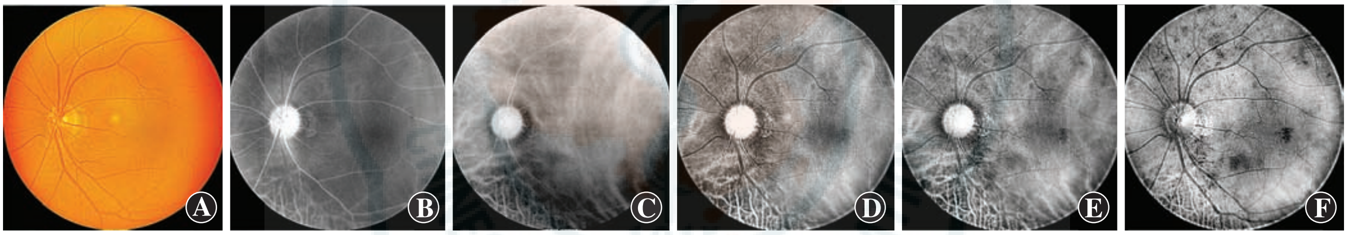

图 3　1 例 C2N3P2 核性白内障 RHA 眼底表现　男,66 岁,左眼,眼轴长度为 23.56 mm,屈光度为+0.25 D　A:红绿光组合(620 nm+550 nm)眼底像中可见视盘及血管,视网膜血管　B:黄琥珀光组合(580 nm+590 nm)光谱视网膜血管图可见视网膜血管轮廓,模拟 FFA　C:红外光组合(760 nm+810 nm)光谱脉络膜血管图可清晰辨别脉络膜血管轮廓,模拟 ICGA　D:光谱 660 nm 眼底像中视网膜血管清晰,可辨认出除黄斑区以外的脉络膜血管,视盘血管不可见　E:光谱 740 nm 眼底像中黄斑区脉络膜血管出现　F:光谱 850 nm 眼底像中脉络膜血管欠清晰,可见脉络膜色素分布

Figure 3　RHA fundus image of C2N3P2 nucleus opacity cataract　Male, 66 years old, left eye, axial length was 23.56 mm, diopter was +0.25 D　A: Fundus imaging of the red and green light combination (620 nm+550 nm)　the optic nerve blood papilla and blood vessels, as well as retinal blood vessels, were clearly visible　B: Retinal blood vessel imaging of the yellow succinate light combination (580 nm+590 nm) profile of retinal blood vessels were clearly visible, simulating FFA　C: Choroid blood vessel imaging of the infrared light combination (760 nm+810 nm) the profile of choroid blood vessels was clearly visible, simulating ICGA of the fundus　D: Fundus imaging at 660 nm retinal blood vessels were sharp and choroid blood vessels, except in the macular area, were distinguishable, while the optic nerve blood papilla and blood vessels were invisible　E: Fundus imaging of 740 nm horoid blood vessels in the macular area were visible　F: Fundus imaging at 850 nm　choroid blood vessels were not clear, while the choroid pigment distribution was visible

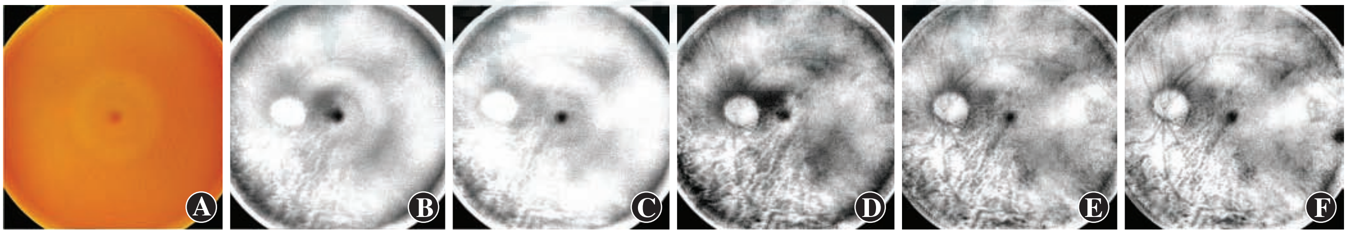

图 4　1 例 C0N4P0 核性白内障 RHA 眼底表现　男,56 岁,右眼,眼轴长度为 25.56 mm,屈光度为 -9.50 D　A:红绿光组合(620 nm+550 nm)眼底像中眼底结构完全不可见　B:光谱 690 nm 眼底像中仅模糊见视盘轮廓及颞上视网膜静脉　C:光谱 740 nm 眼底像,仅模糊见视盘轮廓　D:光谱 780 nm 眼底像中视盘下方脉络膜血管透见,视盘及视网膜中央静脉模糊,余结构不可见　E:光谱 810 nm 眼底像中视网膜中央血管欠清,视盘下方脉络膜血管透见,脉络膜色素模糊　F:光谱 850 nm 眼底像,同 810 nm

Figure 4　RHA fundus image of C0N4P0 nucleus cataract　Male, 56 years old, right eye, axial length was 22.83 mm, diopter was -9.50 D　A: Fundus imaging of the red and green light combination (620 nm+550 nm)　the fundus structure was completely invisible　B: Fundus imaging at 690 nm　only the outline of papilla of optic nerve and retinal vein above the temporal region was obscurely visible　C: Fundus imaging at 740 nm　only the outline of papilla of the optic nerve was obscurely visible　D: Fundus imaging at 780 nm　choroid blood vessels below the optic disk were visible, the papilla of optic nerves and central veins of retina were obscure, and the resting structures were invisible　E: Fundus imaging at 810 nm　central retinal blood vessels were less clear, choroid blood vessels below the optic disk were visible, and the choroid pigment was obscure　F: Fundus imaging at 850 nm　the same as that of fundus imaging at 810 nm

2.5 后囊下混浊白内障组 RHA 眼底图像分析

后囊下混浊白内障组中 RHA 眼底成像清晰度下降，红绿光组合眼底像模糊，光谱 580 nm 处可观察视网膜血管，810 nm 和 850 nm 处可观察视网膜血管、脉络膜血管以及色素分布。C2N2P4 后囊膜下白内障患者红绿光组合图仅可见视盘轮廓及视网膜中央血管大致走行，810 nm 和 850 nm 处可见视网膜血管走行，视网膜动脉颞上分支迂曲，颞侧及视盘下方透见脉络膜血管，部分清晰，部分隐蔽。580 nm 处可见较清晰的视网膜分支血管，因受检者固视差，伪迹遮挡黄斑区（图 5）。

2.6 混合型白内障组 RHA 眼底图像分析

在混合型白内障组中 RHA 眼底成像清晰度下降，红绿光组合眼底图像模糊，850 nm 处可观察到视网膜血管走行，血管反光不可见，脉络膜血管区域性可见。C0N3P3 混合型白内障患者红绿光组合图仅见视盘处视网膜血管，光谱 850、780 和 810 nm 处视网膜血管欠清晰，可见血管大致走行，脉络膜血管透见伴部分隐蔽，脉络膜色素模糊，光谱 580 nm 处眼底像中视网膜中央血管清晰，分支血管欠清晰，视盘血管不可见，黄斑区伪迹遮挡（图 6，表 3）。

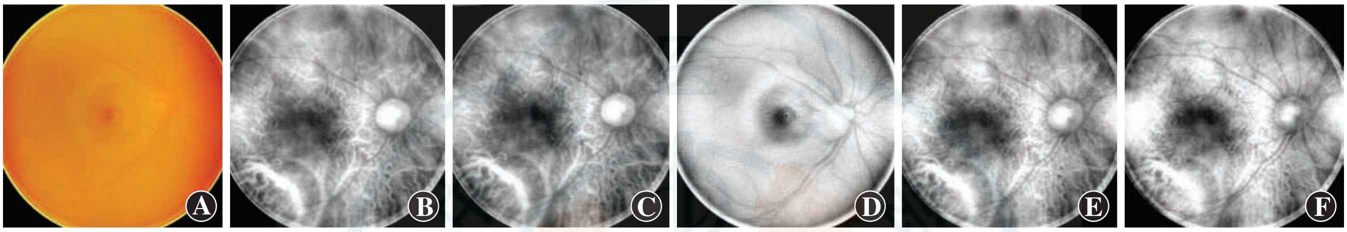

图 5　1 例 C2N2P4 后囊膜下白内障 RHA 眼底表现　女，72 岁，右眼，眼轴长度为 22.83 mm，屈光度为 -4.00 D　A：红绿光组合（620 nm+550 nm）眼底图像中仅视盘及颞上颞下视网膜静脉主干模糊可见，其余血管及黄斑区不可见　B：光谱 760 nm 眼底图像中视网膜静脉欠清，视网膜动脉模糊，除黄斑区外脉络膜血管透见　C：光谱 780 nm 眼底图像，同 760 nm　D：光谱 580 nm 眼底图像中视网膜中央血管欠清，分支血管隐约可见，视网膜血管反光及视盘血管不可见，黄斑区伪迹明显　E：光谱 810 nm 眼底图像，可见模糊视网膜动脉走行，脉络膜血管模糊，脉络膜色素不可见　F：光谱 850 nm 眼底图像，同 810 nm，视网膜中央血管欠清晰，脉络膜血管较 810 nm 图像模糊，脉络膜色素不可见

Figure 5　RHA fundus image of C2N2P4 posterior subcapsular opacity cataract　Female, 72 years old, right eye, axial length was 25.56 mm, diopter was -4.00 D　A: Fundus imaging of the red and green light combination (620 nm+550 nm)　Only the papilla of the optic nerve and retinal vein trunk above and below the temporal region was obscurely visible, while the resting blood vessels and macular area were invisible　B: Fundus imaging at 760 nm　The retinal vein was less clear, while the retinal artery was obscure and the choroid blood vessels, except for the macular area, were visible　C: Fundus imaging at 780 nm　The same as fundus imaging at 760 nm　D: Fundus imaging at 580 nm　The central blood vessels of the retina were less clear, branch blood vessels were indistinctly visible, reflections of retinal blood vessels and blood vessels of papilla of optic nerve were invisible, and the stimulus artifact in the macular area was clear　E: Fundus imaging at 810 nm　An obscure running line of the retinal artery was visible, choroid blood vessels were obscure, and choroid pigment was invisible　F: Fundus imaging at 850 nm　As for fundus imaging at 810 nm, the central blood vessels of retina were less clear, choroid blood vessels were more obscure than fundus imaging at 810 nm, and choroid pigment was invisible

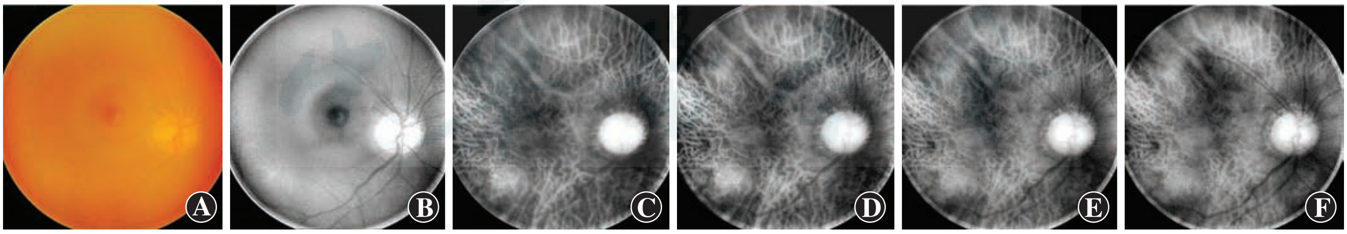

图 6　1 例 C0N3P3 混合型白内障 RHA 眼底表现　男，57 岁，右眼，眼轴长度为 22.15 mm，屈光度为 -3.50 D　A：红绿光组合（620 nm+550 nm）眼底图像中仅见视盘处视网膜血管　B：光谱 580 nm 处眼底图像中视网膜中央血管清晰，分支血管欠清晰，视盘血管不可见，黄斑区伪迹遮挡　C：光谱 690 nm 处眼底图像中脉络膜血管清晰透见，视网膜血管模糊　D：光谱 780 nm 处眼底图像中颞上及颞下视网膜中央静脉欠清晰，脉络膜血管透见　E：光谱 810 nm 处眼底图像，脉络膜血管清晰度较 780 nm 图像降低　F：光谱 850 nm 处眼底图像中脉络膜血管欠清晰，清晰度较 810 nm 处降低，脉络膜色素模糊

Figure 6　RHA fundus image of C0N3P3 hybrid cataract　Male, 57 years old, right eye, axial length was 22.15 mm, diopter was -3.50 D　A: Fundus imaging of the red and green light combination (620 nm+550 nm)　Only the optic nerve blood papilla and retinal vessels at the papilla were visible　B: Fundus imaging at 580 nm　The central blood vessels of retina were clear, branch vessels were less clear, blood vessels of the optic nerve papilla were invisible, and the stimulus artifact sheltered the macular area　C: Fundus imaging at 690 nm choroid blood vessels were clearly visible and blood vessels of the retina were obscure　D: Fundus imaging at 780 nm central retinal veins above and below the temporal region were less clear and choroid blood vessels were visible　E: Fundus imaging at 810 nm　Choroid blood vessels were less clear than fundus imaging at 780 nm　F: Fundus imaging at 850 nm　Choroid blood vessels were less clear than fundus imaging at 810 nm and the choroid pigment was obscure

表 3　不同类型白内障 RHA 眼底表现
Table 3　RHA fundus findings in different types of cataracts

白内障类型	眼数	红绿光组合图	视网膜血管、色素分布、脉络膜血管观察清晰度
皮质混浊	18	模糊	在 590、810 和 580 nm 处可见，其余波长处模糊或不可见
核性混浊	21	核 3 级欠清，核 4 级及以上模糊	在 580、810 和 590 nm 处可见，其余波长处模糊或不可见
后囊下混浊	2	模糊	在 810、850 和 580 nm 处可见，其余波长处模糊或不可见
混合型	4	模糊	在 850 nm 处欠清晰，其余波长处模糊或不可见

注：RHA：多普勒眼底成像仪
Note：RHA：retinal health assessment

3　讨论

本研究发现，当晶状体核混浊达到 4 级及以上，或皮质混浊达到 3 级及以上，或后囊下混浊达到 3 级以上时，常用的红绿彩色眼底照相已无法清晰获取眼底图像。但此时，采用 RHA 的 MSI 系统中部分波长谱段成像仍可以获得视网膜及脉络膜的清晰图像。该结果在国内外既往未见同类报道。

RHA 的 MSI 系统在检查眼底血管异常方面类似于眼底照相，同样具有非侵袭性、快捷、有效的特点[3,16]，但其成像采用的波长谱段范围是目前最大的。短波中绿光 550 nm（获取视网膜色素上皮以内各层图像）与眼底照相相似。既往研究表明，RHA 短波成像谱段中的 580 nm（黄光）能较好地观察浅层及中层视网膜（视网膜血管和神经纤维层）出血、棉絮斑及渗出等病变[3]。多光谱成像能根据不同光吸收来评估视网膜和脉络膜的传输功能，这有助于通过定量测量来更好地理解和诊断眼底疾病[17]。

本研究中发现，RHA 短波成像谱段中的 590 nm 与 580 nm 图像相似，与传统眼底照相技术相比，能清晰地观察到浅中层视网膜的各个细节。600 nm 以外的长波长光可显示黑色素，与眼底照片相比，多光谱 690 nm 图片能够更好地揭示黑色素裂解是否存在及其严重程度[18]。随着波长的增加，特别是大于 670 nm 时，可以观察到深层视网膜结构。近红外和红外波长的影像能分别显示 RPE 和脉络膜血管层的表现[10]。红外光（760 nm～850 nm）对混浊介质的穿透性良好，如混浊晶状体，可获得较为清晰的视网膜图像。本研究中也发现相比于短波长谱段，810 nm 及 850 nm 红外光能观察更多视网膜 RPE 层以及脉络膜层细节，且易穿透混浊的晶状体，可应用于观察白内障患者眼底情况[4]。当晶状体混浊程度高时，患者视力差，固视能力差，RHA 眼底图像黄斑区可见伪迹。

RHA 使用的屈光补偿范围为 -15～15 D[11]。核性白内障屈光指数增加，晶状体屈光力增强，使屈光度增加，因此本研究不采用 -6.00 D 为界，区分高度近视，而是以眼轴长度 27.0 mm 为界排除高度近视患者[12-13]。本研究中发现 13 眼合并高度近视的白内障（眼轴长度大于 27 mm，未纳入本研究），拍摄时聚焦较困难，脉络膜的透见程度增加，即使晶状体混浊程度较低时（如 C0N2P0），视网膜图像模糊不清，且拍摄所得范围欠完整，仅适宜观察后极部，RHA 眼底成像欠清，这有待 RHA 设备今后发展来解决。

综上所述，部分白内障患眼因晶状体严重混浊，明显影响了常用的红绿光组合眼底成像，但 RHA 中 580、590、810 和 850 nm 光谱成像仍可以获取眼底图像，有助于及时发现白内障手术前眼底疾病及评估手术预后。

利益冲突　所有作者均声明不存在任何利益冲突

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读者 · 作者 · 编者

本刊对论文中统计学方法描述的要求

研究论文如有量化测试指标时须有统计学分析的内容，并在方法部分提供统计学方法的描述，反应变量为单变量时请提供测量指标数据资料的性质（如计量数据资料及计数数据资料的表达方式）、多个样本计量数据资料正态分布检验方法的名称及方差齐性检验方法的名称、实（试）验设计方法及与之相匹配的统计学设计（如配对设计、成组设计、交叉设计、析因设计、正交设计等）、与统计设计相应的统计方法名称（如 t 检验、方差分析）以及检验水准。选择方差分析统计设计时应根据单因素或多因素设计选择正确的方法，不宜简单套用单因素方差分析。反应变量为双变量时，应根据实（试）验设计正确选择简单直线相关分析、回归分析或其他方法，不宜简单套用直线相关分析。统计学的检验水准请提供为双侧检验或单侧检验。论文结果部分的统计学分析内容可用相应的图表表达。

统计学符号的著录执行 GB/T 3358.1—2009/ISO 3534-1:2006《统计学词汇及符号》的有关规定，统计学符号一律采用斜体，如样本量用 n；样本的算术平均数用英文$\bar{x}$；中位数用英文斜体大写 M，标准差用英文 s，样本均数的标准误用英文小写 $\sigma\bar{x}$，t 检验用英文小写 t，F 检验用英文大写 F，卡方检验用希文小写 χ^2，Pearson 线性相关分析相关系数用英文小写 r，Spearman 秩相关分析相关系数用 r_s 确定系数用 R^2，自由度用希文小写 v；概率用英文大写 P；检验水准用 α。统计结果的解释和表达采用对比组或比较对象之间差异有统计学意义的描述方法，而不用对比组之间差异具有显著性（或非常显著性）的描述。论文的统计学分析结果提倡提供统计学检验量值和 P 值的具体数据，如不能提供 P 值的具体数据时，必须提供统计学检验量值如χ^2 值、t 值、F 值等。当涉及总体参数（如总体均数、总体率等）时，在给出显著性检验结果的同时，请给出 95%可信区间（CI）。

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