·文献综述·

# 近视与脉络膜厚度的相关性

韩 聪,杨 义,张文芳

**引用**:韩聪,杨义,张文芳. 近视与脉络膜厚度的相关性. 国际眼科杂志 2022;22(3):407-411

**基金项目**:国家自然科学基金资助项目(No.82060180);甘肃省自然科学基金项目(No.21JR1RA140)
**作者单位**:(730000)中国甘肃省兰州市,兰州大学第二临床医学院 兰州大学第二医院
**作者简介**:韩聪,女,在读硕士研究生,研究方向:眼底病。
**通讯作者**:张文芳,女,博士,主任医师,博士研究生导师,研究方向:眼底病. zhwenf888@163.com
收稿日期:2021-07-09 修回日期:2022-01-19

**摘要**

近视是引起视力损害的一个全球性公共问题,它的发生发展常常伴随着眼部各个组织结构的变化,尤其是病理性近视,涉及巩膜、脉络膜及视网膜等退行性变化。近年来,随着近视患病率越来越高,近视病理机制的探索及防治已成为全球性无法忽视的重要问题。近视的发生发展涉及多种因素的参与,最终会造成严重的视觉损害。脉络膜作为眼部重要的血管组织,其厚度的变化被证明在近视发生发展中承担着至关重要的角色。为全面有效预防控制近视,尤其是高度近视的发生发展,近视性脉络膜厚度的变化及其相关机制应成为近视病理机制的主要研究方向之一。本文通过对近年来国内外学者对近视与脉络膜厚度变化的相关研究进行综述,来探讨脉络膜厚度、脉络膜血管系统、脉络膜分子学变化与近视、近视相关并发症及近视性视觉功能损害的关系,为近视的防控及干预方式提供新的思路。

**关键词**:近视;脉络膜厚度;脉络膜血管
DOI:10.3980/j.issn.1672-5123.2022.3.11

## Correlation between myopia and choroidal thickness

**Cong Han, Yi Yang, Wen-Fang Zhang**

**Foundation items**: National Natural Science Foundation of China (No. 82060180); Natural Science Foundation of Gansu Province (No.21JR1RA140)
The Second Clinical Medical College of Lanzhou University; the Second Hospital of Lanzhou University, Lanzhou 730000, Gansu Province, China
**Correspondence to**: Wen-Fang Zhang. The Second Clinical Medical College of Lanzhou University; the Second Hospital of Lanzhou University, Lanzhou 730000, Gansu Province, China. zhwenf888@163.com
Received: 2021-07-09 Accepted: 2022-01-19

## Abstract

• Myopia is a global public problem that causes visual impairment. Its occurrence and development are often accompanied by changes in the various structures of the eye, especially pathological myopia, which involves degenerative changes in the sclera, choroid, and retina. In recent years, with the increasing prevalence of myopia, the exploration of pathological mechanism and the prevention and treatment of myopia have become an important issue that cannot be ignored in the world. The occurrence and development of myopia involves the participation of many factors and can cause serious visual damage. As an important vascular tissue in the eye, the thickness change of choroid has been proved to play a vital role in the occurrence and development of myopia. In order to comprehensively and effectively prevent and control the occurrence and development of myopia, especially high myopia, the change of myopic choroidal thickness and its related mechanisms should be one of the main directions of the pathological mechanism of myopia. This article reviews the research of changes of myopia choroidal thickness by domestic and foreign scholars in recent years, to discuss the relationship between choroidal thickness, choroidal vasculature, choroidal molecular changes and myopia, myopia - related complications, and myopia - related visual impairment. Provide new ideas on prevention and intervention of myopia.

• KEYWORDS: myopia; choroidal thickness; choroidal blood vessels

**Citation**: Han C, Yang Y, Zhang WF. Correlation between myopia and choroidal thickness. *Guoji Yanke Zazhi* (*Int Eye Sci*) 2022; 22(3):407-411

## 0 引言

近视(myopia)是引起视力损害的一个全球性公共问题,其发病率逐年增加,尤其在中国等一些亚洲国家。2018年我国儿童青少年近视的患病率已达到53.6%,预计到2030年将会达到61.8%,高中生甚至达到90.5%[1],远超全球水平[2]。近视通常在儿童早期至中期发展,也可能在青少年期或成年期发展。眼轴增长在发育过程中与屈光状态最密切相关,眼轴较长的患者更容易近视。尽管近视状态可以被框架镜、隐形眼镜、角膜塑型镜及屈光手术等矫正,但它常伴随眼部各个组织结构的变化,尤其是病理性近视,涉及巩膜、脉络膜及视网膜等退行性变化。目前,近视的发生机制尚未完全清楚,但随着近年来光学相干断层扫描(optical coherence tomography, OCT)等各种技

术设备的使用,眼后节组织结构的观察不再局限于以动物实验为主的解剖学及病理等方面的探索,因此脉络膜在近视发生发展中的作用也逐渐被广泛重视。

脉络膜是眼球中主要的血管组织,位于巩膜和视网膜中间,在大多数物种的脉络膜在组织学上分为五层,从内(视网膜)侧开始:Bruch 膜、毛细血管层、中血管层、大血管层和脉络膜上腔,除 Bruch 膜外,其他层主要是血管。脉络膜还包含多种非血管细胞,包括黑色素细胞、成纤维细胞、非血管平滑肌细胞和免疫活性细胞等,由胶原蛋白支持[3]。脉络膜主要为外层视网膜提供氧气和营养,还有吸收光、体温调节和调节眼压等功能。近年来,许多研究发现脉络膜的厚度变化和分泌功能在响应视觉刺激与调节巩膜生长中发挥了重要的作用[4],这为近视发生机制及治疗方法提供了新的思路。

## 1 脉络膜厚度随眼球生长的变化

1995 年,一些学者对鸡眼进行了离焦干预,发现可引起脉络膜厚度的变化,首次引起了广泛的关注[5]。随后在其他动物眼中关于脉络膜厚度变化的研究也逐渐被开展。近年来,国内外许多学者利用 OCT 对不同背景、不同年龄段人群的脉络膜厚度进行了研究,并报道正常人群中心凹下脉络膜厚度在 203~350μm,越往周边越薄,鼻侧最薄[6-8],且脉络膜厚度的调节存在昼夜节律,午夜最薄,正午最厚,上下波动约 40μm[9-10],这种波动主要是由脉络膜基质腔的大小变化决定的。许多对持续性非近视人群的横断面研究发现,在儿童及青少年时期,脉络膜厚度与年龄呈正相关,成年后与年龄呈负相关[8,11-12],影响非近视成年人脉络膜厚度的因素主要是年龄,男性脉络膜厚度大于女性[7,13],人种间没有差异[14-15]。

## 2 近视引起的脉络膜厚度变化及其对视觉功能的影响

**2.1 近视与脉络膜厚度** 大多数物种包括人类在出生时眼球的屈光状态均为远视状态,在发育过程中,正视作用不断调整眼轴长度和屈光度以保持正常的视力,直到青春期以后停止生长。然而,在基因及环境的作用下,部分人向近视发展、眼轴不断增长,因此眼球各个组织结构也在不断发生变化。研究表明,脉络膜会随视网膜聚焦的短期变化而变化,调节自身厚度使视网膜移动形成清晰的图像[16],对眼睛施加近视离焦,会引起脉络膜变厚,远视离焦则相反[17],以此来达到视物正视化。该机制在早期近视的代偿及发展中起到了重要的作用。

然而,持续性近视的存在会引起脉络膜厚度的不可逆变化。研究发现,随着近视性屈光度数及眼轴长度的增加[18-19],脉络膜厚度随之减少,高度近视患者这种关系尤为明显[20],且在整个黄斑区域变化不均匀,但也有研究认为眼轴与脉络膜厚度之间不存在这种相关性[21]。Hoseini-Yazdi 等[22]对年轻近视患者的脉络膜厚度进行测量,发现与正视眼相比,以黄斑为中心 55°范围的总脉络膜厚度减少了 16%,在黄斑中心凹最明显,变薄 19%,离黄斑区越远,脉络膜变薄的差异越小,变薄约 10%,相对于正视儿童,儿童近视眼黄斑中心凹脉络膜厚度减少了 10%~16%[19,23],比成人近视眼变薄程度小,可能与未成年时期,年龄与脉络膜厚度的关系有关。而黄斑中心凹外脉络膜厚度,无论是儿童还是成人,均表现出鼻侧最薄,其次是下方,颞侧最厚[24]。对于视盘区的研究表明,儿童期近视及成人非高度近视的发生并不会影响视盘周围脉络膜厚度,而成人高度近视患者视盘周围脉络膜厚度变薄[25]。结合眼睛生长特征,推测可能由于近视在生长过程中眼球轴向伸长对视网膜、脉络膜和巩膜形成轴向机械拉伸,在此过程中视网膜神经纤维层及脉络膜层变薄[26],视网膜色素上皮层(retinal pigment epithelium, RPE)及 Bruch 膜并无结构变化[27-28],使拉伸不均匀,从而产生上述脉络膜厚度独特的地形变化。

另外,Xiong 等[29]研究发现,新发展的近视患者脉络膜厚度的减少比持续性近视更多,可能与眼轴的快速增长有关,对于持续性近视,基线轻度近视患者的脉络膜厚度变化与眼轴长度变化之间的关系要强于基线中度至高度近视患者。因此,在轻度近视眼中,是否存在脉络膜厚度的代偿机制,可抵消眼轴增长带来的脉络膜变薄作用,是未来广大学者需要探索的问题。

**2.2 脉络膜厚度的变化与视觉功能的相关性** 近视造成的视觉功能下降是目前防治的重点内容,与近视度数、视网膜功能、脉络膜及近视相关的并发症均有不同程度的相关性。过去许多研究探索了近视引起的脉络膜厚度的变化与视觉功能的关系,一定程度上,不同的学者有不同的意见。一些学者的研究发现,视敏度的降低与近视度数增加引起的脉络膜变薄相一致[30-31]。Wang 等[32]同样发现,高度近视患者脉络膜厚度变化可预测眼底漆裂纹的发生及发展,而漆裂纹则预示着最佳矫正视力的下降。对于高度近视而无眼底病变的患者,脉络膜厚度变薄还会引起对比敏感度降低[33]。但也有学者的研究表明,在年轻的高度近视眼中,脉络膜厚度并不是视力的独立预测指标,脉络膜变薄也可与良好的视力相兼容[34],同时 Gupta 等[35]提出年轻近视患者脉络膜变薄可足够滋养同样变薄的视网膜,以此维持正常的视觉功能。因此,脉络膜厚度变化对近视患者视觉功能的判断存在较大的不确定性及争议性,但由于病理性近视脉络膜的变化已被证明,脉络膜厚度仍然可能是研究高度近视视觉功能损害的发病机制的重要参数。

## 3 近视性脉络膜厚度变化的相关机制

**3.1 脉络膜血管系统** 血管是脉络膜的主要组成部分,研究证明,大于 30 岁的健康人群的脉络膜血管密度随着年龄不断减少[36],脉络膜血管指数随年龄的增加而降低[37]。而脉络膜血管管腔面积的变化可直接影响脉络膜厚度,脉络膜血流异常或受损可能导致视网膜受损[38]。脉络膜血管结构的变化已在小鸡和豚鼠的近视模型中被多位学者描述,结果表明,近视可能会导致脉络膜血管直径减小,血管密度降低[39-40]以及血流量减少[41],脉络膜变薄。Fitzgerald 等[42]对鸡眼进行形觉剥夺后,脉络膜变薄,脉络膜血流量减少,解除形觉剥夺的作用后,脉络膜厚度及血流量呈现短暂性增高。对豚鼠的研究同样表明远视散焦引起的脉络膜厚度的变化是由于脉络膜灌注的调节变化所致[43]。动物实验的研究为近视性脉络膜厚度的变化机制提供了新的思路。近年来,研究者们对人群脉络膜脉管系统进行了研究,通过超声检查和吲哚菁绿血管造影(indocyanine green angiography, ICGA)评估近视患者脉络膜变化的研究表明,脉络膜脉管系统和循环的密度降低了[44-46];对近视患者眼底分区域脉络膜毛细血管灌注的研究显示,与正常人群相比,近视患者脉络膜毛细血管灌注显著降低,且视盘周围降低程度大于黄斑中心凹、大于中心凹旁区域[47],病理性近视患者尤为明显,且与眼轴成负相关[48]。推测可能是由于近视患者随着眼轴的增长,

视网膜、脉络膜和巩膜的生物力学拉伸会导致血管变直和变窄、脉络膜毛细血管网的整体疏散及脉络膜血流阻力增大,从而导致脉络膜毛细血管密度降低[46,48-49],脉络膜基质及血管变薄[50],进而脉络膜变薄。因此,近视对血管成分的影响可能会进一步引起脉络膜厚度减少,而脉络膜循环受损无法供应视网膜时,视力可能会随之受影响,可能部分解释了高度近视眼中视功能丧失的原因。

**3.2 脉络膜相关蛋白分子变化** 在实验动物的近视模型的研究中,国内外学者一直在探索关于脉络膜厚度变化的可能蛋白及分子机制。在小鸡短期形觉剥夺的眼睛中发现,脉络膜上腔液体中蛋白质含量减少,脉络膜厚度在相应解剖区域变薄[51],推测蛋白质作为渗透剂调节脉络膜上腔水含量,从而调节外脉络膜的厚度。RPE 也可能参与脉络膜厚度的调节,主要可能通过调节视网膜和脉络膜之间的离子和液体交换[3,52]。蛋白聚糖的作用已被证明是与屈光性脉络膜厚度相关的分子之一[53],而视黄酸作为另一被证明的分子,主要由脉络膜合成,可能参与调节巩膜蛋白聚糖的合成[54]。已知巩膜蛋白聚糖参与巩膜的生长重塑,而实验诱导的生长缓慢的眼球具有较厚的脉络膜,可合成更多的视黄酸,从而减少巩膜蛋白聚糖的合成。反过来,可以说明视黄酸抑制了巩膜蛋白聚糖的合成速度,也为近视患者从脉络膜变化到巩膜变化提供了明确的因果关系。视黄酸受体表达的变化也已经被检测到,其中该受体在视网膜的表达随形觉剥夺而增加[55]。另外,Rada 等[56]证明 *HAS2* 基因是主要的视黄酸基因,在调节脉络膜厚度的过程中发挥了重要的作用。

视网膜对视觉刺激产生反应,促进脉络膜分泌生长调节因子,从而使脉络膜发生变化。据报道,脉络膜胰高血糖素在近视发展中作为抑制信号存在[57],而胰岛素与胰高血糖素具有相反作用,也可能参与近视发展中脉络膜厚度的调节,并可能通过 RPE 依赖性机制,例如对体外鸡眼组织的研究发现,在存在 RPE 的眼组织中添加的胰岛素会使脉络膜变薄,而不存在 RPE 的则没有此作用[58]。近几年,学者们发现血管内皮生长因子 A(vascular endothelial growth factor-A, VEGF-A)在脉络膜血管壁上高表达,在响应近视离焦引起的脉络膜增厚的过程中,VEGF-A可能发挥了大的作用[59]。脉络膜中转化生长因子 TGF-β3 基因随着远视离焦的增加而表达增加[60]。此外,多巴胺似乎也参与了近视性脉络膜厚度变化的过程,Nickla 等[61]对小鸡进行玻璃体内注射两种多巴胺受体激动剂阿扑吗啡和喹吡罗,发现脉络膜短暂增厚,而近视与多巴胺及多巴胺受体的相关性已被广泛研究报道,进一步说明了多巴胺在近视性脉络膜厚度变化中可能起重要作用。

## 4 近视矫正对脉络膜厚度的影响

研究表明,未成年近视患者配戴角膜塑形镜后眼轴增长,黄斑中心凹下脉络膜厚度增加[62-63],鼻侧变厚最少,颞侧最多,且在停止配戴后恢复[63],推测是与脉络膜自然较厚的地方有更大的能力响应离焦带来的快速变化[16,64],周边脉络膜也增厚,但配戴期间并未显示长期持续增厚[65]。巩膜加固术矫正近视后的早期,手术眼和对侧眼的脉络膜厚度均显著增加,而脉络膜厚度的增加也刺激了巩膜基质的胶原生物合成活性和胶原合成,增强了手术对近视进展的抑制作用[66]。准分子激光矫正近视术后,脉络膜变厚,且在早期调节减弱的情况下增厚更明显[67]。

## 5 近视性脉络膜厚度变化与近视相关并发症的关系

近视引起的脉络膜厚度的变化会引起眼底病变的发生,在高度近视患者中更为常见,例如近视性黄斑病变、脉络膜新生血管及中心性浆液性脉络膜视网膜病变等。研究发现,黄斑区脉络膜厚度变薄会增加近视性黄斑变性的严重程度[68]、脉络膜新生血管(choroidal neovascularization, CNV)的形成及漆裂纹的发生发展[32,69]。脉络膜厚度与近视性黄斑病变的严重程度和视觉效果之间有很强的联系,表明脉络膜厚度是近视性黄斑变性改变的重要生物标志,而对高度近视患者的脉络膜厚度进行监测将有助于检测和监测近视性黄斑病变[16]。近年来 OCT 血管成像的出现可更好地对近视性脉络膜新生血管进行检测[70],El Matri 等[71]研究发现,与没有 CNV 的眼相比,有 CNV 的高度近视眼的脉络膜厚度明显变薄,因此可以推测脉络膜变薄可能在高度近视继发 CNV 的发病机制中起作用,另外,他们认为病理性近视可能是 50 岁以下患者 CNV 的主要原因。由此可见,近视引起的脉络膜厚度的变化不止局限于形态学的改变,还会引起严重的并发症,造成视觉功能的丧失。

## 6 总结与展望

综上所述,近视发生发展可能通过脉络膜血管的变化及脉络膜相关蛋白分子的变化引起脉络膜厚度变薄,引起一系列严重的并发症,使视功能受损。面对全球近视患病率的逐年增加,探索完善近视发生发展的分子机制、明确近视眼中视网膜、脉络膜及巩膜之间的调节变化机制对近视防控尤为重要。因此,脉络膜厚度与近视的关系更提示广大研究者近视矫正不止于矫正视力的低下,更重要的是在此基础上研发可以作用于脉络膜的新型药物或治疗仪器,以指导临床应用,通过调控脉络膜厚度来达到预防近视发生、延缓近视发展、阻止近视并发症的发生、保护眼底及维持正常的视功能,这是未来应该去关注的新方向,也是 21 世纪近视防控国情下的一个重要的目标,争取能早日攻破近视这一全球性难题。

**参考文献**

1 陈军,何鲜桂,王菁菁,等. 2021 至 2030 年我国 6~18 岁学生近视眼患病率预测分析. 中华眼科杂志 2021;57(4):261-267

2 Myopia, Who-Bhvigsmo J, Mariotti SP, *et al*. The impact of myopia and high myopia. Report of the Joint World Health Organization-Brien Holden Vision Institute Global Scientific Meeting on Myopia 2015

3 Nickla DL, Wallman J. The multifunctional choroid. *Prog Retin Eye Res* 2010;29(2):144-168

4 Summers JA. The choroid as a sclera growth regulator. *Exp Eye Res* 2013;114:120-127

5 Wildsoet C, Wallman J. Choroidal and scleral mechanisms of compensation for spectacle lenses in chicks. *Vis Res* 1995;35(9):1175-1194

6 Sanchez-Cano A, Orduna E, Segura F, *et al*. Choroidal thickness and volume in healthy young white adults and the relationships between them and axial length, ammetropy and sex. *Am J Ophthalmol* 2014;158(3):574-583

7 Wei WB, Xu L, Jonas JB, *et al*. Subfoveal choroidal thickness: the Beijing Eye Study. *Ophthalmology* 2013;120(1):175-180

8 Margolis R, Spaide RF. A pilot study of enhanced depth imaging optical coherence tomography of the choroid in normal eyes. *Am J Ophthalmol* 2009;147(5):811-815

9 Tian Y, Wildsoet CF. Diurnal fluctuations and developmental changes in ocular dimensions and optical aberrations in young chicks. *Invest*

*Ophthalmol Vis Sci* 2006;47(9):4168-4178
10 Nickla DL, Wildsoet C, Wallman J. Visual influences on diurnal rhythms in ocular length and choroidal thickness in chick eyes. *Exp Eye Res* 1998;66(2):163-181
11 Xiong S, He X, Deng J, *et al*. Choroidal Thickness in 3001 Chinese Children Aged 6 to 19 Years Using Swept-Source OCT. *Sci Rep* 2017;7:45059
12 Read SA, Collins MJ, Vincent SJ, *et al*. Choroidal thickness in childhood. *Invest Ophthalmol Vis Sci* 2013; 54(5):3586-3593
13 Li XQ, Larsen M, Munch IC. Subfoveal choroidal thickness in relation to sex and axial length in 93 Danish university students. *Invest Ophthalmol Vis Sci* 2011;52(11):8438-8441
14 Karapetyan A, Ouyang P, Tang LS, *et al*. Choroidal thickness in relation to ethnicity measured using enhanced depth imaging optical coherence tomography. *Retina* 2016;36(1):82-90
15 Bafiq R, Mathew R, Pearce E, *et al*. Age, Sex, and Ethnic Variations in Inner and Outer Retinal and Choroidal Thickness on Spectral-Domain Optical Coherence Tomography. *Am J Ophthalmol* 2015;160(5):1034-1043
16 Read SA, Fuss JA, Vincent SJ, *et al*. Choroidal changes in human myopia: insights from optical coherence tomography imaging. *Clin Exp Optom* 2019; 102(3):270-285
17 Moderiano D, Do M, Hobbs S, *et al*. Influence of the time of day on axial length and choroidal thickness changes to hyperopic and myopic defocus in human eyes. *Exp Eye Res* 2019;182:125-136
18 Duan F, Yuan Z, Deng J, *et al*. Choroidal Thickness and Associated Factors among Adult Myopia: A Baseline Report from a Medical University Student Cohort. *Ophthalmic Epidemiol* 2019;26(4):244-250
19 Read SA, Collins MJ, Vincent SJ, *et al*. Choroidal thickness in myopic and nonmyopic children assessed with enhanced depth imaging optical coherence tomography. *Invest Ophthalmol Vis Sci* 2013;54(12):7578-7586
20 Flores-Moreno I, Lugo F, Duker JS, *et al*. The relationship between axial length and choroidal thickness in eyes with high myopia. *Am J Ophthalmol* 2013; 155(2):314-319
21 Jin P, Zou H, Xu X, *et al*. Longitudinal changes in choroidal and retinal thicknesses in children with myopic shift. *Retina* 2019;39(6):1091-1099
22 Hoseini-Yazdi H, Vincent SJ, Collins MJ, *et al*. Wide-field choroidal thickness in myopes and emmetropes. *Sci Rep* 2019;9(1):3474
23 Moussa M, Sabry D, Soliman W. Macular choroidal thickness in normal Egyptians measured by swept source optical coherence tomography. *BMC Ophthalmol* 2016;16:138
24 Harb E, Hyman L, Gwiazda J, *et al*. Choroidal Thickness Profiles in Myopic Eyes of Young Adults in the Correction of Myopia Evaluation Trial Cohort. *Am J Ophthalmol* 2015;160(1):62-71
25 Deng J, Li X, Jin J, *et al*. Distribution Pattern of Choroidal Thickness at the Posterior Pole in Chinese Children With Myopia. *Invest Ophthalmol Vis Sci* 2018;59(3):1577-1586
26 Zhao L, Wang Y, Chen CX, *et al*. Retinal nerve fibre layer thickness measured by Spectralis spectral-domain optical coherence tomography: The Beijing Eye Study. *Acta Ophthalmol* 2014;92(1):e35-41
27 Jonas JB, Holbach L, Panda-Jonas S. Bruch's membrane thickness in high myopia. *Acta Ophthalmol* 2014;92(6):470-474
28 Chui TY, Zhong Z, Burns SA. The relationship between peripapillary crescent and axial length: Implications for differential eye growth. *Vis Res* 2011;51(19):2132-2138
29 Xiong S, He X, Zhang B, *et al*. Changes in Choroidal Thickness Varied by Age and Refraction in Children and Adolescents: A 1-Year Longitudinal Study. *Am J Ophthalmol* 2020;213:46-56
30 Alzaben Z, Cardona G, Zapata MA, *et al*. Interocular asymmetry in choroidal thickness and retinal sensitivity in high myopia. *Retina* 2018;38(8):1620-1628
31 Zaben A, Zapata M, Garcia-Arumi J. Retinal sensitivity and choroidal thickness in high myopia. *Retina* 2015;35(3):398-406
32 Wang NK, Lai CC, Chou CL, *et al*. Choroidal thickness and biometric markers for the screening of lacquer cracks in patients with high myopia. *PLoS One* 2013;8(1):53660
33 García-Domene MC, Luque MJ, Díez-Ajenjo MA, *et al*. Chromatic and achromatic visual fields in relation to choroidal thickness in patients with high myopia: A pilot study. *J Fr Ophtalmol* 2018;41(2):109-115
34 Pang CE, Sarraf D, Freund KB. Extreme choroidal thinning in high myopia. *Retina* 2015;35(3):407-415
35 Gupta P, Saw SM, Cheung CY, *et al*. Choroidal thickness and high myopia: a case-control study of young Chinese men in Singapore. *Acta Ophthalmol* 2015;93(7):585-592
36 Fujiwara A, Morizane Y, Hosokawa M, *et al*. Factors Affecting Choroidal Vascular Density in Normal Eyes: Quantification Using En Face Swept-Source Optical Coherence Tomography. *Am J Ophthalmol* 2016;170:1-9
37 Sonoda S, Sakamoto T, Yamashita T, *et al*. Luminal and stromal areas of choroid determined by binarization method of optical coherence tomographic images. *Am J Ophthalmol* 2015;159(6):1123-1131
38 Li C, Fitzgerald MEC, Del MN, *et al*. Defective Choroidal Blood Flow Baroregulation and Retinal Dysfunction and Pathology Following Sympathetic Denervation of Choroid. *Invest Ophthalmol Vis Sci* 2018;59(12):5032-5044
39 Hirata A, Negi A. Morphological changes of choriocapillaris in experimentally induced chick myopia. *Graefes Arch Clin Exp Ophthalmol* 1998;236(2):132-137
40 Junghans BM, Crewther SG, Liang H, *et al*. A role for choroidal lymphatics during recovery from form deprivation myopia? *Optom Vis Sci* 1999;76(11):796-803
41 Shih YF, Fitzgerald ME, Norton TT, *et al*. Reduction in choroidal blood flow occurs in chicks wearing goggles that induce eye growth toward myopia. *Curr Eye Res*1993;12(3):219-227
42 Fitzgerald ME, Wildsoet CF, Reiner A. Temporal relationship of choroidal blood flow and thickness changes during recovery from form deprivation myopia in chicks. *Exp Eye Res* 2002;74(5):561-570
43 Lu F, Zhou X, Jiang L, *et al*. Axial myopia induced by hyperopic defocus in guinea pigs: A detailed assessment on susceptibility and recovery.*Exp Eye Res* 2009;89(1):101-108
44 Moriyama M, Ohno-Matsui K, Futagami S, *et al*. Morphology and long-term changes of choroidal vascular structure in highly myopic eyes with and without posterior staphyloma. *Ophthalmology* 2007;114(9):1755-1762
45 Quaranta M, Arnold J, Coscas G, *et al*. Indocyanine green angiographic features of pathologic myopia. *Am J Ophthalmol* 1996;122(5):663-671
46 Akyol N, Kükner AS, Ozdemir T, *et al*. Choroidal and retinal blood flow changes in degenerative myopia. *Can J Ophthalmol* 1996;31(3):113-119
47 Mastropasqua R, Viggiano P, Borrelli E, *et al*. *In Vivo* Mapping of the Choriocapillaris in High myopia: a Widefield Swept Source Optical Coherence Tomography Angiography. *Sci Rep* 2019;9(1):18932
48 Mo J, Duan A, Chan S, *et al*. Vascular flow density in pathological

myopia: an optical coherence tomography angiography study. *BMJ Open* 2017;7(2):013571

49 Al-Sheikh M, Phasukkijwatana N, Dolz-Marco R, *et al*. Quantitative OCT Angiography of the Retinal Microvasculature and the Choriocapillaris in Myopic Eyes. *Invest Ophthalmol Vis Sci* 2017;58(4):2063-2069

50 Gupta P, Thakku SG, Saw SM, *et al*. Characterization of Choroidal Morphologic and Vascular Features in Young Men With High Myopia Using Spectral-Domain Optical Coherence Tomography. *Am J Ophthalmol* 2017;177:27-33

51 Pendrak K, Papastergiou GI, Lin T, *et al*. Choroidal vascular permeability in visually regulated eye growth. *Exp Eye Res* 2000;70(5):629-637

52 Rymer J, Wildsoet CF. The role of the retinal pigment epithelium in eye growth regulation and myopia: a review. *Vis Neurosci* 2005;22(3):251-261

53 Wallman J, Wildsoet C, Xu A, *et al*. Moving the retina: choroidal modulation of refractive state. *Vis Res* 1995;35(1):37-50

54 Mertz JR, Wallman J. Choroidal retinoic acid synthesis: a possible mediator between refractive error and compensatory eye growth. *Exp Eye Res* 2000;70(4):519-527

55 Morgan IG. The biological basis of myopic refractive error. *Clin Exp Optom* 2003;86(5):276-288

56 Rada JA, Wiechmann AF, Hollaway LR, *et al*. Increased hyaluronan synthase-2 mRNA expression and hyaluronan accumulation with choroidal thickening: response during recovery from induced myopia. *Invest Ophthalmol Vis Sci* 2010;51(12):6172-6179

57 Feldkaemper MP, Schaeffel F. Evidence for a potential role of glucagon during eye growth regulation in chicks. *Vis Neurosci* 2002;19(6):755-766

58 Sheng C, Zhu X, Wallman J. *In vitro* effects of insulin and RPE on choroidal and scleral components of eye growth in chicks. *Exp Eye Res* 2013;116:439-448

59 Mathis U, Ziemssen F, Schaeffel F. Effects of a human VEGF antibody (Bevacizumab) on deprivation myopia and choroidal thickness in the chicken. *Exp Eye Res* 2014;127:161-169

60 Zhang Y, Raychaudhuri S, Wildsoet CF. Imposed Optical Defocus Induces Isoform-Specific Up-Regulation of TGFβ Gene Expression in Chick Retinal Pigment Epithelium and Choroid but Not Neural Retina. *PLoS One* 2016;11(5):0155356

61 Nickla DL, Totonelly K, Dhillon B. Dopaminergic agonists that result in ocular growth inhibition also elicit transient increases in choroidal thickness in chicks. *Exp Eye Res* 2010;91(5):715-720

62 张瑞琪, 杨积文. 近视青少年单眼角膜塑形术后脉络膜厚度变化. 中华眼视光学与视觉科学杂志 2020;22(8):613-617

63 Li Z, Hu Y, Cui D, *et al*. Change in subfoveal choroidal thickness secondary to orthokeratology and its cessation: a predictor for the change in axial length. *Acta Ophthalmol* 2019;97(3):454-459

64 Chen Z, Xue F, Zhou J, *et al*. Effects of Orthokeratology on Choroidal Thickness and Axial Length. *Optom Vis Sci* 2016;93(9):1064-1071

65 Gardner DJ, Walline JJ, Mutti DO. Choroidal Thickness and Peripheral Myopic Defocus during Orthokeratology. *Optom Vis Sci* 2015;92(5):579-588

66 Tarutta EP, Markossian GA, Sianosyan AA, *et al*. Choroidal thickness in children with myopia and its changes after surgical strengthening of the sclera. *Vestn Oftalmol* 2020;136(3):10-17

67 Li M, Cheng H, Yuan Y, *et al*. Change in choroidal thickness and the relationship with accommodation following myopic excimer laser surgery. *Eye (Lond)* 2016;30(7):972-978

68 Wong CW, Phua V, Lee SY, *et al*. Is Choroidal or Scleral Thickness Related to Myopic Macular Degeneration? *Invest Ophthalmol Vis Sci* 2017;58(2):907-913

69 Wang S, Wang Y, Gao X, *et al*. Choroidal thickness and high myopia: a cross-sectional study and meta-analysis. *BMC Ophthalmol* 2015;15:70

70 Querques L, Giuffrè C, Corvi F, *et al*. Optical coherence tomography angiography of myopic choroidal neovascularisation. *Br J Ophthalmol* 2017;101(5):609-615

71 El Matri L, Bouladi M, Chebil A, *et al*. Choroidal thickness measurement in highly myopic eyes using SD-OCT. *Ophthalmic Surg Lasers Imaging* 2012;43(6 Suppl):38-43