African Vision and Eye Health
ISSN: (Online) 2410-1516, (Print) 2413-3183

Foveal hypoplasia in oculocutaneous albinism: An optical coherence tomography study

Authors:
Ethan Pillay[1]
Nishanee Rampersad[1]

Affiliations:
[1]Discipline of Optometry, School of Health Sciences, University of KwaZulu-Natal, Durban, South Africa

Corresponding author:
Nishanee Rampersad,
rampersadn@ukzn.ac.za

Dates:
Received: 13 Aug. 2022
Accepted: 11 Apr. 2023
Published: 09 Nov. 2023

How to cite this article:
Pillay E, Rampersad N. Foveal hypoplasia in oculocutaneous albinism: An optical coherence tomography study. Afr Vision Eye Health. 2023;82(1), a807. https://doi.org/10.4102/aveh.v82i1.807

Background: Albinism is an inherited condition characterised by a lack of pigmentation. Foveal hypoplasia, which occurs because of disruptions in normal foveal development, is commonly observed in albinism. Previous studies using optical coherence tomography (OCT) have reported variable foveal morphology in individuals with oculocutaneous albinism.

Aim: To evaluate foveal hypoplasia in individuals with oculocutaneous albinism using OCT.

Setting: Eye clinic at the University of KwaZulu-Natal (UKZN).

Methods: The study used a descriptive design and included 30 participants with a clinical diagnosis of oculocutaneous albinism from the UKZN eye clinic. The iVue 100 OCT device was used to assess foveal morphology and measure the foveal thickness. Descriptive statistics were used to summarise the data.

Results: Most participants had wheat blond hair colour (n = 27), grey iris colour (n = 20) and horizontal jerk nystagmus (n = 24). Only one participant had grade 1 foveal hypoplasia, where a shallow foveal pit was observed. The remaining participants had grade 3 (n = 14) or grade 4 (n = 15) foveal hypoplasia, wherein the foveal pit and outer segment lengthening were absent. The binocular visual acuity (VA) and central foveal thickness ranged from 0.50 LogMAR to 1.12 LogMAR and 236 µm to 367 µm, respectively. There was no correlation between central foveal thickness and VA.

Conclusion: Foveal morphology in oculocutaneous albinism varies and ranges from absent development (fovea plana) to near normal development (shallow pit). Spectral-domain OCT devices help evaluate foveal hypoplasia.

Contribution: Foveal hypoplasia is common in oculocutaneous albinism and can be evaluated using OCT.

Keywords: foveal hypoplasia; oculocutaneous albinism; optical coherence tomography; foveal morphology; central foveal thickness.

Introduction

Albinism is an inherited condition characterised by a lack of pigmentation because of impaired melanin biosynthesis and is more common in Africa than elsewhere in the world.[1,2] A recent study estimated that almost 14 000 people in South Africa have albinism, with a prevalence of 1 in every 4000 in the black population.[1] There are different sub-types of albinism because of mutations in several known genes.[3,4] Furthermore, albinism can have either an autosomal recessive or X-linked recessive mode of inheritance and be associated with systemic disorders such as Chediak-Higashi syndrome, Hermansky-Pudlak syndrome and Waardenburg syndrome. Generally, ocular albinism involves the eyes only, while oculocutaneous albinism involves the skin, hair and eyes. Individuals with albinism present with several ocular features including nystagmus, strabismus, reduced vision, chiasmal misrouting, hypopigmentation of the iris and fundus, loss of the foveal avascular zone and annular reflex, photophobia, reduced depth perception, ametropia and partial or absent formation of the foveal pit.[5,6]

Foveal hypoplasia describes the persistence of the inner retinal layers, which are normally absent at the fovea, across the central macular.[7,8] This occurs because of disruptions in the stages of normal foveal development and results in an underdeveloped fovea that impacts visual function.[8,9,10,11] Development of the fovea in humans begins during gestation. It involves the movement of the cone photoreceptors towards the incipient fovea (centripetal displacement) together with lateral movement of the inner retinal layers towards the periphery (centrifugal displacement) as well as foveal cone specialisation.[12,13] Foveal hypoplasia is a common characteristic

of albinism. It has also been observed in retinopathy of prematurity, aniridia, microphthalmos, nanophthalmos and achromatopsia or as an isolated finding.[7,9,13] Traditional methods for evaluating foveal hypoplasia include fundus examination, histology and fluorescein angiography.[13,14] Optical coherence tomography (OCT) is a non-invasive imaging method that rapidly produces high-resolution cross-sectional images of ocular structures in real time. Considering the advancements in OCT imaging since its introduction in the early 1990s, this technique is now widely used to provide detailed retinal images for various anomalies including foveal hypoplasia.[11,13,15,16]

The study aimed to evaluate foveal hypoplasia, detected with OCT, in individuals with oculocutaneous albinism. Previous studies in South Africa have reported on the impact of optical correction and coloured overlays on visual acuity (VA), contrast sensitivity and reading performance in individuals with albinism.[17,18] Other researchers have focused on how individuals with albinism use services related to social development and skin and eye care in South Africa.[19] As there is a high prevalence of albinism in Africa and previous studies on the continent have not described aspects of foveal morphology, this study adds to the literature documenting foveal morphology in individuals with albinism from the African context.

Research methods and design

The study used a descriptive quantitative design and convenience sampling to recruit participants. The study population comprised of patients with albinism who presented at the UKZN eye clinic for ocular examination and management services from May to October 2019. The nature of the study and procedures were explained to participants and adult parents or guardians (in cases of participants younger than 18 years). Written informed consent and assent (if needed) were obtained before participation. A pilot study involving five participants, not included in the final sample, was undertaken to standardise the data collection procedures.

All participants underwent an examination that included: (1) observation (skin, hair and iris colour and presence of any strabismus or head tilt), (2) review of ocular and medical history, (3) distance and near VA, (4) cover test, (5) refraction (objective and subjective) and ocular health assessment using ophthalmoscopy, (6) rebound tonometry and (7) slit lamp biomicroscopy. The distance and near VA were assessed using the Low Vision Resource Centre and Bailey-Lovie word reading charts, respectively. Participants were encouraged to use their habitual head posture in instances of nystagmus and/or strabismus and monocular testing was achieved using a high-powered convex lens for fogging. The binocular distance VA measurement was preferred over the monocular measurements as the latter may be degraded because of occlusion, monocular fogging, latent nystagmus and/or amblyopia.[4,11] Specific clinicians were responsible for the different tests within the examination protocol to ensure standardisation of the instructions, recording and endpoints. Participants with any condition other than albinism, history of ocular surgery and/or trauma, currently on medication, media opacities and younger than 10 years or older than 30 years were excluded.

As this study did not include molecular and/or genetic testing, the diagnosis of albinism was based on a clinical recommendation. According to Kruijt et al.,[2] the presence of minor and major clinical criteria can be used to diagnose albinism, particularly in the absence of molecular and/or genetic tests. The minor criteria include hypopigmentation of the skin and hair, nystagmus, fundus hypopigmentation and foveal hypoplasia (grade 1). The major criteria include chiasmal misrouting, ocular (iris or fundus) hypopigmentation and foveal hypoplasia (grade 2 or more). The presence of clinical findings was used to diagnose albinism, as has been done in other studies.[4,5,9,20] Although individuals with albinism do not consistently present with all of the characteristics associated with the condition,[2,5] descriptions of the clinical phenotype are well documented in the literature.[4]

The Optovue iVue 100 optical coherence tomographer was used to assess retinal morphology and to measure retinal thickness. This spectral domain device has a scanning speed of 26 000 axial scans per second and frame rate of 256–4096 axial scans per frame.[21] This spectral domain device's axial and transverse resolutions are 5 µm and 8 µm, respectively. The retinal map scan protocol (6 mm × 6 mm) consisting of a raster pattern of 13 horizontal line scans (six with 512 axial scans and seven with 1024 axial scans) was used. Using a pre-programmed algorithm, this device automatically determines retinal thickness as the distance between the retinal pigment epithelium layer (outer limit) and the inner limiting membrane (inner limit).[21] When capturing the scans, participants were instructed to fixate on the internal fixation target with their habitual head posture to allow for their null point and preferred retinal focus. Scans with motion artefacts, scan quality indices less than 40, incorrectly placed segmentation lines or were labelled as 'poor' on the screen display were excluded. To ensure standardisation, only one trained clinician performed the retinal scans. The same clinician reviewed each scan to assess the scan quality index, verify the segmentation lines of the outer and inner retinal boundaries and check for motion artefacts before accepting the scan and continuing to the following scan. Both eyes of participants were scanned at least three times, and the average of the central foveal thickness measurements was computed.

The retinal map scans (tomograms) were also used to grade the degree of foveal hypoplasia using a grading scheme proposed by Thomas et al.[11] This structural grading scheme is based on the presence or absence of the key morphological features associated with the normal foveal development process as detected using OCT imaging.[8,22] The four features in a normal fovea include: (1) extrusion of the plexiform layers, (2) presence of a foveal pit, (3) outer segment lengthening and (4) outer nuclear layer widening.[8,11] In the grading scheme, all four grades of foveal hypoplasia show

incursion of the inner retinal layers (ganglion cell layer, inner plexiform layer, inner nuclear layer and outer plexiform layer) at the fovea, implying that formation of the foveal pit is either incomplete or absent.[11,22] Features of grade 1 foveal hypoplasia include a shallow foveal pit, outer segment lengthening and outer nuclear layer widening. Grade 2 foveal hypoplasia consists of all the features in grade 1 foveal hypoplasia except the presence of a shallow foveal pit. Grade 3 foveal hypoplasia consists of all the features in grade 2 foveal hypoplasia except the presence of outer segment lengthening. Grade 4 foveal hypoplasia consists of the features in grade 3 foveal hypoplasia except for the presence of the outer nuclear layer widening. This foveal hypoplasia grading scheme outlines the different stages of altered foveal development characterised by the varying grades of foveal hypoplasia wherein grade 1 represents the most developed fovea. In contrast, grade 4 represents the least developed fovea (fovea plana).[8,11,22] Two clinicians, who were masked to the participant's data, independently graded each participant's foveal hypoplasia and then compared their findings. Any discrepancies were resolved through discussion to finalise the grade of foveal hypoplasia.

Data were captured and analysed with the Statistical Package for Social Sciences (SPSS) version 27. The Shapiro-Wilk test and histograms were used to assess the age, VA and central foveal thickness data normality. Data are described using summary statistics such as frequency counts, percentages, medians and ranges. Spearman's rho correlation coefficient test assessed the correlation between VA and central foveal thickness. A 95% significance level was used where probability (p) values less than 0.05 were considered statistically significant.

Ethical considerations

Ethical clearance to conduct this study was obtained from the University of KwaZulu-Natal Biomedical Research Ethics Committee (No. BE139/19) and adhered to the tenets of the Declaration of Helsinki.

Results

The sample consisted of 30 black participants, with more females (n = 21) than males (n = 9). The median age of participants was 20 years (range: 14–30 years; interquartile range [IQR]: 7 years). Table 1 summarises the phenotype and ocular characteristics of the sample. The majority of participants had wheat blond hair colour (n = 27), grey iris colour (n = 20) and horizontal jerk nystagmus (n = 24). Seven participants had a 'combination' iris colour where at least two different colours (either grey, brown, hazel or blue) were present simultaneously. Half of the sample presented with manifest strabismus where esotropia (n = 12) was more common than exotropia (n = 3). All participants (n = 30) had pale creamy white skin colour and iris transillumination defects.

Figure 1 shows examples of cross-sectional retinal scans showing the different grades of foveal hypoplasia. All grades of foveal hypoplasia had multiple inner retinal layers that crossed the foveal centre (Figure 1a, Figure 1b and Figure 1c). Only one participant had grade 1 foveal hypoplasia showing the presence of a rudimentary shallow foveal pit, widening and bulging upwards of the outer nuclear layer at the fovea and lengthening of the outer segment (Figure 1a). Of the remaining participants, 14 had grade 3 foveal hypoplasia showing only the presence of a widening of the outer nuclear layer at the fovea (Figure 1b). Fifteen participants had grade 4 foveal hypoplasia where none of the tomograms showed a foveal pit, widening of the outer nuclear layer and lengthening of the outer segment (Figure 1c). Furthermore, the retinal tomograms in this group of participants showed widespread thickening with little differentiation between the macular and fovea (Figure 1c).

TABLE 1: Phenotype and ocular characteristics of participants (N = 30).

Phenotypic and ocular characteristics	Frequency	
	n	%
Hair colour		
Wheat blond	27	90.0
Light brown	3	10.0
Skin colour		
Creamy white	30	100.0
Iris colour		
Grey	20	66.7
Brown	1	3.3
Hazel	1	3.3
Blue	1	3.3
Combination	7	23.3
Strabismus		
Orthotropia	15	50.0
Esotropia	12	40.0
Exotropia	3	10.0
Nystagmus		
Horizontal jerk	24	80.0
Horizontal pendular	6	20.0
Iris transillumination defects		
Present	30	100.0
Absent	0	0.0

Table 2 shows the median and IQR values for the best-corrected distance VA and central foveal thickness stratified for the different grades of foveal hypoplasia. The distance VA measurement was 1.10 LogMAR for the one participant with grade 1 foveal hypoplasia. Furthermore, the central foveal thickness measurements for the right and left eyes were 284 µm and 298 µm, respectively. Participants with grade 4 foveal hypoplasia had poorer median distance VA measurements than those with grade 3 foveal hypoplasia (Table 2). The median central foveal thickness measurements for the right and left eyes were similar in participants with grade 3 and grade 4 foveal hypoplasia with inter-eye differences of less than 15 µm (Table 2). The distance VA and central foveal thickness measurements ranged from 0.50 LogMAR to 1.12 LogMAR and 236 µm to 367 µm respectively. There was no correlation between distance VA and the central foveal thickness measurements ($r \leq 0.188$; $p \geq 0.319$).

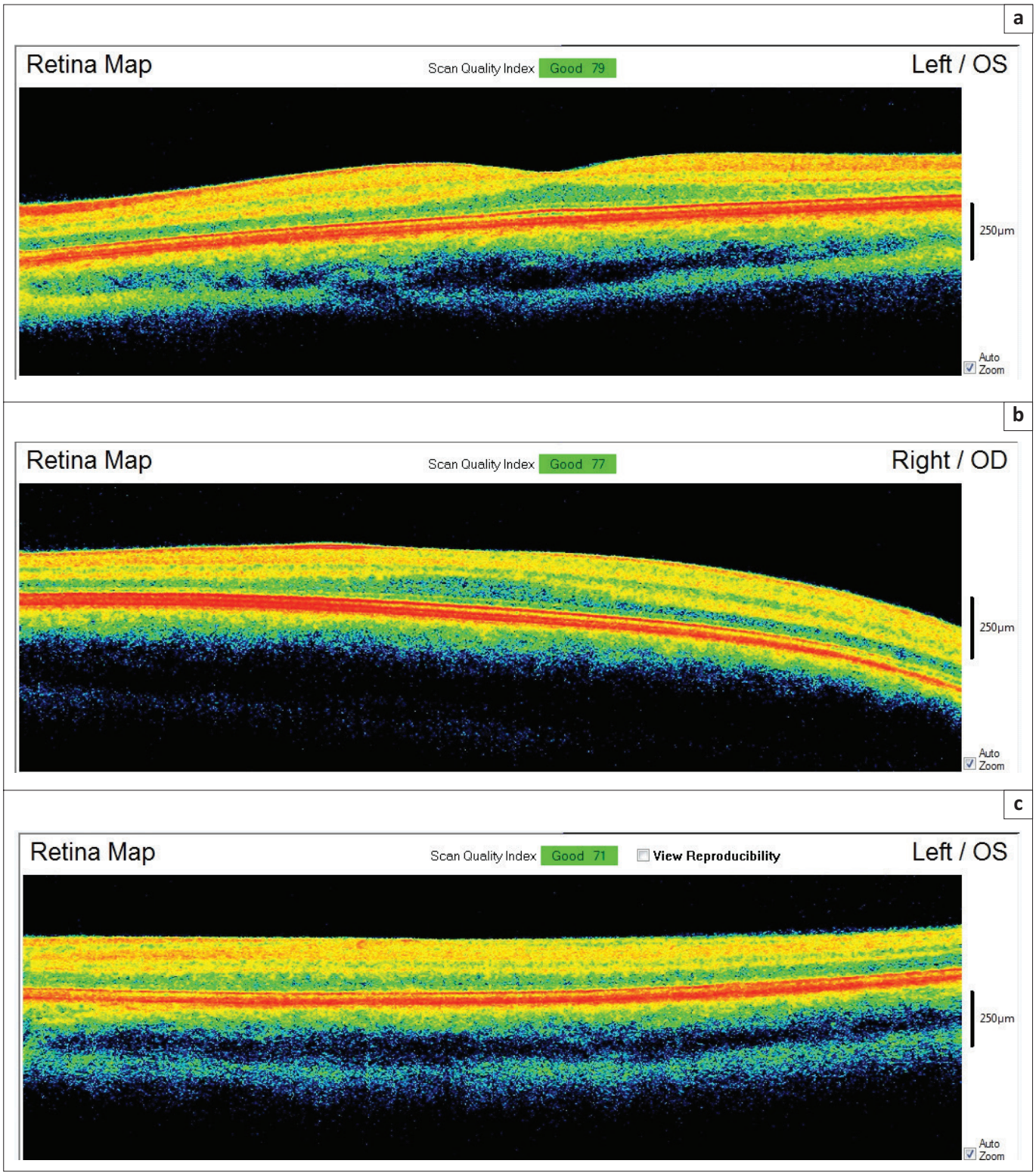

FIGURE 1: Cross-sectional retinal scans showing foveal morphology. (a) Participant 21 with grade 1 foveal hypoplasia. (b) Participant 1 with grade 3 foveal hypoplasia. (c) Participant 30 with grade 4 foveal hypoplasia.

Discussion

Foveal hypoplasia is a common finding in individuals with oculocutaneous albinism.[2,3,6,15] Two early observational case reports, which used time-domain OCT devices, described foveal hypoplasia in individual cases of oculocutaneous albinism.[14,15] Meyer et al.[15] reported that the retinal tomograms in a 10-year-old female showed hyperreflective red-coloured layers at the fovea while the photoreceptors showed a hyporeflective blue colour adjacent to hyperreflective retinal pigment epithelium. Furthermore, the tomograms showed no foveal pit, the persistence of multiple inner retinal layers across the fovea and foveal thickness measurements greater than 300 µm. The researchers suggested that the increased foveal

TABLE 2: Medians and interquartile range for visual acuity and central foveal thickness in the different grades of foveal hypoplasia.

Variables	Grade 1 foveal hypoplasia† (mean) (*n* = 1)	Grade 3 foveal hypoplasia (*n* = 14)		Grade 4 foveal hypoplasia (*n* = 15)	
		Mean	IQR	Mean	IQR
Distance visual acuity (LogMAR)	1.10	0.76	0.19	0.90	0.28
Right eye central fovea thickness (µm)	284	292	18	284	25
Left eye central fovea thickness (µm)	298	281	22	295	45

LogMAR, logarithm of the minimum angle of resolution; IQR, interquartile range.

†, Grade 1 foveal hypoplasia does not have any interquartile range values.

thickness measurements are likely because of a lack of differentiation of the fovea and macular owing to multiple ganglion cell layers extending across the fovea.[15] Similar findings were described by McGuire et al.[14] in their case report of a 79-year-old male wherein the retinal tomograms showed persistence of the outer nuclear layer, inner nuclear layer and ganglion cell layer in the expected location of the fovea. Despite the valuable data provided in these early case reports, retinal imaging with spectral domain devices in individuals with foveal hypoplasia may provide more detailed information on foveal morphology owing to their higher resolution, faster scanning speeds and better reliability.[13,23]

In this study, all participants except one (Participant 21) had grades 3 and 4 foveal hypoplasia characterised by lack of a foveal pit and outer segment lengthening. Other studies, which used the same foveal hypoplasia grading scheme, noted that albinism is usually associated with higher grades (2, 3 or 4) of foveal hypoplasia.[5,11] Individuals with foveal hypoplasia, particularly those with higher grades, show loss of the characteristic foveal pit because the inner retinal layers continue to cross the central macula without thinning.[24] Despite this, the literature on foveal morphology in individuals with albinism is variable, wherein a spectrum of findings ranging from absent foveal development (observed as increased thickness and plana appearance of the macular) to near normal foveal development (observed as a shallow foveal pit) have been reported.[4,6,7,23] For example, Harvey et al.[4] noted that a rudimentary foveal pit was observed in only three out of 11 participants when imaged with OCT. The observation that a foveal pit was absent in most participants in the study by Harvey et al.[4] is interesting, considering that all participants in their study had relatively good VA (binocular VA of 20/50 or better), suggesting some degree of foveal development. McAllister et al.[23] also reported a range of foveal development based on the tomograms of six participants with albinism when imaged with OCT. The tomograms showed a plana appearance of the macular area (*n* = 2), doming of the macular (*n* =1) and shallow foveal pit with some degree of inner retinal layer thinning (*n* = 3), suggesting that there is a continuum of foveal development in albinism.[23] Furthermore, it has been proposed that this variability in foveal morphology is likely explained by the level of melanin, genetic mutations and the different subtypes of albinism in affected individuals.[23]

In this study, only one participant had grade 1 foveal hypoplasia. It is interesting to note that despite the retinal images of this participant showing a rudimentary shallow foveal pit implying partial thinning of the inner retinal layers, the best-corrected distance VA was reduced (1.10 LogMAR). This finding is in contrast with that of McCafferty et al.,[3] who found that individuals with albinism that showed features consistent with rudimentary foveal development had better VA measurements. Park and Oh[9] noted that their sample of individuals with foveal hypoplasia had variable VA measurements (0.22–0.82 LogMAR). They suggested that this likely resulted from other factors associated with albinism. McCafferty et al.[3] noted that four individuals in their sample who showed better VA did not have nystagmus. This suggests that the poor VA in the participant with grade 1 foveal hypoplasia in the present study may be because of other mechanisms of reduced vision in albinism (nystagmus, amblyopia, strabismus, reduced pigmentation and light scattering) rather than altered foveal development.[11,20,25] However, this speculation is based only on one participant and therefore visual function and clinical characteristics in a larger sample of individuals with grade 1 foveal hypoplasia should be investigated to understand the cause of reduced vision. Nonetheless, the clinical and retinal image findings in the participant with grade 1 foveal hypoplasia support previous reports of the phenotypic variability noted in individuals with albinism.[2,10,11]

Several studies have reported on structure-function relationships in individuals with oculocutaneous albinism with VA and OCT findings (retinal thickness and/or grades of foveal hypoplasia) being commonly investigated.[3,25] This may be because of developments in imaging techniques, such as spectral domain OCT, allowing for high-resolution retinal evaluation. Furthermore, an enhanced understanding of which clinical and/or retinal imaging variables may be the best determinants of visual function would be necessary for individuals with albinism, clinicians and researchers to better understand the visual prognosis, make decisions concerning examination and management as well as for initiatives aimed at pharmacological interventions.[3,22,25] Overall, individuals with higher grades of foveal hypoplasia have poorer VA owing to more significant alterations in the normal foveal development process.[7,9,11] Furthermore, some studies[4,22,25] have found a significant correlation between VA and central foveal thickness and/or grade of foveal hypoplasia, while other studies[3,7,16,20] have reported no significant correlation. The results of the present study are consistent with the findings in the latter group of studies, as there was no significant correlation between VA and central foveal thickness.

The poor VA findings of participants in this study are consistent with the findings of other studies.[9,11] This may be explained by almost all participants showing higher grades of foveal hypoplasia, implying more alterations in the foveal development process. Interestingly, Park and Oh[9] observed that individuals in their study with the same grade of foveal hypoplasia (grade 3) had dissimilar VA measurements (0.22 and 0.70 LogMAR). Chong et al.[24] reported that individuals with suspected ocular albinism that had almost identical retinal morphology findings

showed variable VA measurements. Furthermore, Marmor et al.[10] noted that participants with absent foveal pits and avascular zones had relatively good VA (20/25 to 20/50), while Wilk et al.[6] noted that their participants with almost normal foveal morphology had similar VA measurements (20/25 to 20/70). Some of these researchers[9,10] enrolled only a few participants (n = 4 to 10) in their studies; therefore, their results should be interpreted cautiously. Despite this, the extent to which the foveal morphology can be used as a predictor of VA remains to be determined, and this is likely because of the inter-subject variability in the phenotypic characteristics noted in individuals with albinism.[6] Future studies consisting of larger samples of individuals with albinism and additional tests (genetic analysis, adaptive optics scanning laser ophthalmoscopy, OCT angiography and contrast sensitivity) may help to address these inconsistencies and better understand how retinal anatomy correlates with visual function.

Limitations of this study include a small sample size and a narrow age range of participants. In spite of this, this study reports on foveal hypoplasia in more individuals with oculocutaneous albinism than in previous reports.[3,9,15] Even though all participants were black South Africans, implying a limitation in ethnic variability, the results of the study provide baseline information on foveal hypoplasia in these individuals. As only one participant had grade 1 foveal hypoplasia, the retinal thickness and VA findings in this grade of foveal hypoplasia should interpreted with caution. Similar studies with a larger number of individuals with grade 1 foveal hypoplasia would be useful to verify the results noted in the present study. Furthermore, the limited number of participants in the different grades of foveal hypoplasia, particularly grades 1 and 2, did not allow for a statistical comparison of VA findings across the different grades. Future studies should enrol a larger cohort of individuals with albinism and assess for the differences in visual function across the different grades of foveal hypoplasia. The study used a spectral domain OCT device to image the fovea and a foveal hypoplasia grading system that is increasingly used because it is validated, has good inter-grader reliability and can be easily applied in a clinical setting.[8,9,11,22]

Conclusion

The present study used the spectral domain OCT to image the retina in individuals with oculocutaneous albinism. The foveal tomograms revealed that hallmark features typically observed at the fovea are absent in these individuals. When the findings related to the phenotypic characteristics, particularly VA and foveal morphology, are considered, it suggests a broad spectrum of clinical and retinal imaging findings in individuals with oculocutaneous albinism consistent with reports of other studies.[3,6,10,23,24] Most participants had higher grades of foveal hypoplasia (grades 3 and 4), wherein the foveal pit and outer segment lengthening were absent, and the inner retinal layers continued to cross the fovea without thinning. Furthermore, there was no correlation between distance VA and the central foveal thickness measurements. This study reaffirms the use of spectral domain OCT to evaluate foveal hypoplasia in individuals with albinism.

Acknowledgements

The authors acknowledge Mr Nyika Mtemeri for assistance with the statistical analysis, Thiroshnee Naidoo, Khadija Asmal, Lilitha Maliwa and Sinenhlanhla Mchunu for assistance in data collection and thank all participants for participating in this study.

Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

E.P. was the study leader. N.R. provided supervision and feedback on the study. E.P. and N.R. wrote the manuscript.

Funding information

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Data availability

New data were collected, analysed and presented for this study. Data that support the findings of this study are available from the corresponding author, N.R., upon reasonable request.

Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any affiliated agency of the authors.

References

1. Kromberg JGR, Manga P, Kerr R. Children with oculocutaneous albinism in Africa: Characteristics, challenges and medical care. S Afr J Child Health. 2020;14(1): 50–54. https://doi.org/10.7196/SAJCH.2020.v14.i1.1608
2. Kruijt CC, De Wit GC, Bergen AA, Florijn RJ, Schalij-Delfos NE, Van Genderen MM. The phenotypic spectrum of albinism. Ophthalmology. 2018;125(12):1953–1960. https://doi.org/10.1016/j.ophtha.2018.08.003
3. McCafferty BK, Wilk MA, McAllister JT, et al. Clinical insights into foveal morphology in albinism. J Pediatr Ophthalmol Strabismus. 2015;52(3):167–172. https://doi.org/10.3928/01913913-20150427-06
4. Harvey PS, King RA, Summers CG. Spectrum of foveal development in albinism detected with optical coherence tomography. J AAPOS. 2006;10(3):237–242. https://doi.org/10.1016/j.jaapos.2006.01.008
5. Brücher VC, Heiduschka P, Grezebach U, Eter N, Biermann J. Distribution of macular ganglion cell layer thickness in foveal hypoplasia: A new diagnostic criterion for ocular albinism. PLoS One. 2019;14(11):1–13. https://doi.org/10.1371/journal.pone.0224410
6. Wilk MA, MaAllister JT, Cooper RF, et al. Relationship between foveal cone specialization and pit morphology in albinism. Invest Ophthalmol Vis Sci. 2014;55(7):4186–4198. https://doi.org/10.1167/iovs.13-13217
7. Bringmann A, Barth T, Ziemssen F. Morphology of foveal hypoplasia: Hyporeflective zones in the Henle fiber layer of eyes with high-grade foveal hypoplasia. PLoS One. 2022;17(4):1–21. https://doi.org/10.1371/journal.pone.0266968

8. Thomas MG, Papageorgiou E, Kuht HJ, Gottlob I. Normal and abnormal foveal development. Br J Ophthalmol. 2022;106(5):539–599. https://doi.org/10.1136/bjophthalmol-2020-316348
9. Park KA, Oh SY. Clinical characteristics of high grade foveal hypoplasia. Int Ophthalmol. 2013;33(1):9–14. https://doi.org/10.1007/s10792-012-9664-8
10. Marmor MF, Choi SS, Zawadzki RJ, Werner JS. Visual insignificance of the foveal pit: Reassessment of foveal hypoplasia as fovea plana. Arch Ophthalmol. 2008;126(7):907–913. https://doi.org/10.1001/archopht.126.7.907
11. Thomas MG, Kumar A, Mohammad S, et al. Structural grading of foveal hypoplasia using spectral domain optical coherence tomography; a predictor of visual acuity? Ophthalmology. 2011;118(8):1653–1660. https://doi.org/10.1136/bjophthalmol2020-316348
12. Hendrickson AE, Yuodelis C. The morphological development of the human fovea. Ophthalmology. 1984;91(6):603–612. https://doi.org/10.1016/s0161-6420(84)34247-6
13. Kondo H. Foveal hypoplasia and optical coherence tomographic imaging. Taiwan J Ophthalmol. 2018;8(4):181–188. https://doi.org.10.4103/tjo.tjo_101_18
14. McGuire DE, Weinreb RN, Goldbaurn MH. Foveal hypoplasia demonstrated in vivo with optical coherence tomography. Am J Ophthalmol. 2003;135(1):112–114. https://doi.org/10.1016/S0002-9394(02)01923-2
15. Meyer CH, Lapolice DJ, Freedman SF. Foveal hypoplasia in oculocutaneous albinism demonstrated by optical coherence tomography. Am J Ophthalmol. 2002;133(3):409–410. https://doi.org/10.1016/s0002-9394(01)01326-5
16. Holmström G, Eriksson U, Hellgren K, Larsson E. Optical coherence tomography is helpful in the diagnosis of hypoplasia. Acta Ophthalmol. 2010;88(4):439–442. https://doi.org/10.1111/j.1755-3768.2009.01533.x
17. Jhetam S, Mashige KP. Ocular findings and vision status of learners with oculocutaneous albinism. Afr Vision Eye Health. 2019;78(1):1–6. https://doi.org/10.4102/aveh.v78i1.466
18. Makgaba NT, Oduntan OA. Perceived effects of coloured overlays on reading material in persons with albinism. S Afr Optom. 2008;67(3):118–124. https://doi.or/10.4102/aveh.v67i3.189
19. Zungu Z, Mashige KP. Utilisation of eye and skin care, and social services among persons with albinism in Ulundi, KwaZulu-Natal, South Africa. Afr Vision Eye Health. 2019;78(1):1–5. https://doi.org/10.4102/aveh.v78i1.484
20. Hu Z, Wang K, Bertsch M, et al. Correlation between electroretinography, foveal anatomy and visual acuity in albinism. Doc Ophthalmol. 2019;139(1):21–32. https://doi.org/10.1007/s10633-019-09692-9
21. Optovue. iVue100 user's manual version 1.9. Fremont, CA: Optovue; 2011.
22. Rufai SR, Thomas MG, Purohit R, et al. Can structural grading of foveal hypoplasia predict future vision in infantile nystagmus? : A longitudinal study. Ophthalmology. 2020;127(4):492–500. https://doi.org/10.1016/j.ophtha.2019.10.037
23. McAllister JT, Dubis AM, Tait A, et al. Arrested development: High-resolution imaging of foveal morphology in albinism. Vision Res. 2010;50(8):810–817. https://doi.org/10.1016/j.visres.2010.02.003
24. Chong GT, Farsiu S, Freedman SF, et al. Abnormal foveal morphology in ocular albinism imaged with spectral-domain optical coherence tomography. Arch Ophthalmol. 2009;127(1):37–44. https://doi.org/10.1001/archophthalmol.2008.550
25. Seo JH, Yu YS, Kim JH, Choung HK, Heo JW, Kim SJ. Correlation of visual acuity with foveal hypoplasia grading by optical coherence tomography in albinism. Ophthalmology. 2007;114(8):1547–1551. https://doi.org/10.1016/j.ophtha.2006.10.054