3D vs 2D qualitative and semiquantitative evaluation of the glaucomatous optic disc atrophy using computer-assisted stereophotography

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Abstract

Background and purpose Real colour documentation of the optic nerve head (ONH) is one of the most important methods to identify the early progression of glaucomatous optic nerve damage. This study compares the qualitative and semiquantitative evaluation of ONH photographs, using a 3D time-multiplexing system and conventional 2D photography, visualised on a computer monitor.

Patients and methods Stereophotographs of the ONH were converted by special software in a 3D file. The same images were shown in 2D and 3D to 22 subjects with different training grades (residents and ophthalmologists). The evaluation based on a standardised questionnaire, containing semiquantitative parameters of the ONH. A weighted score for quality of ONH assessment counted the correct answers of the observers to compare their evaluation in 2D to the one made in 3D.

Results All of the observers achieved a significant better evaluation of the ONH with 3D than with 2D images. No significant differences were observed between both groups. Classification errors with respect to the 'gold standard' were lower for 3D measurements as compared with 2D measurements ($P=0.007$). No significant differences were observed between the gold standard and residents or ophthalmologists for the ONH size, but for the *c/d* ratio the stereoscopic images lead to better results.

Conclusion This study showed a better evaluation of parameters associated with the glaucomatous ONH atrophy with 3D images

compared with 2D, independent of the clinical training grade. The computer-based evaluation of the ONH atrophy by using a time-multiplexing system (shutter-glasses) may improve the diagnosis of glaucoma patients.

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Keywords: 3D; time-multiplexing stereophotography; optic nerve head evaluation; glaucoma diagnosis; telemedicine

Introduction

Clinical examination of the optic nerve head (ONH) is one of the most important examinations to confirm the diagnosis of primary open angle glaucoma.¹ Nerve fibre polarimetry and scanning laser tomography may produce various measurements, but their false coloured images fail to reflect the clinical ophthalmologic impression of the ONH. Computer-assisted 3D time-multiplexing stereophotography represents a digital system for the stereo visualization of 3D pictures. Its files can easily be transmitted via internet for stereoscopic evaluation anywhere. This may be important for glaucoma screening and telemedical purposes.²

The aim of this study is to compare the evaluation of ONH true-colour and high-resolution photographs using a time multiplexing system in 3D to conventional 2D photographs visualised on a computer monitor and presented to two groups of ophthalmologists with different training grades.

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The time-multiplexing system provides the capability to send and receive stereoscopic ONH photos per internet in a stereo data format (jps). The new digital technology enables the observer to acquire enough visual information, including stereovision, for a qualitative and semiquantitative evaluation of the ONH, using pictures taken with a standard fundus camera. Investigating two groups with differing expertise, the question was whether this inexpensive system would be suitable for residency training, for example.

Patients and methods

ONH photographs

Fifteen-degree fundus sequential stereo photographs of the ONH from patients of the Erlangen Glaucoma Registry were used in this study. Diapositives were taken with a conventional fundus camera type Zeiss 76955 and a Kodak Select Series 200 film and then converted digitally by a SprintScan 35 Plus Film (Polaroid, MA, USA) with a 675 dpi number of pixels. The 12 chosen images of the ONH in different stages of primary glaucoma patients^{1,3–5} were shown to the observers in two different sessions in 2D and then in 3D with a delay of 1 week. The selected stereo photographs were generated by 3D Pix software (Nuvision, USA), which converted two 2D images (jpeg) into 3D (jps) ones. A jps-file (joint photographic stereoimage) consists of two jpeg (joint photographic expert group) files that were superimposed, and aligned vertically and horizontally.

3D PIX software (Version 3.0b by Nuvision, USA) allows to edit and show 2D pictures stereoscopically in, among others, a time multiplexing form. To present the stereo photographs, shutter glasses are required for the observers. This system generates the left/right eye

information by 'blanking out' one of the eyes alternatively.

The *hardware* consisted of a PC (550 MHz, 32 MB graphics) combined with a 21' tube monitor type EIZO with a refreshing rate of 120 MHz. For examination of the pictures stereoscopically, observers used wireless stereo shutter glasses with Liquid Crystal Technology (Revelator, ELSA, Germany). The choice of the stereophotographs was based on the patients' data of the Erlangen Glaucoma Registry. We chose patients with a glaucomatous ONH atrophy (defined by rim loss): four patients with stage I (concentric rim loss), four patients with stage II (rim notches), and four with stage III (notches over three clock hours) (according to Jonas, patient data: Table 1).^{1,3–5} For evaluation of the morphology of the ONH, a questionnaire, containing semiquantitative parameters, was used by all observers during the test (Table 2).

The clinical importance of every 3D morphological structure of the ONH (named as parameter), which is relevant for glaucoma diagnosis, was weighted. Every correct answer was loaded with 1 point multiplied with a factor of importance, according to its relevance to clinical glaucoma diagnosis (see above). The evaluated parameters were classified and weighted as follows:

1 point: Lamina cribrosa visibility.

2 points: Stage and form of the ONH, presence of signs of arterial hypertension: morphology of retinal vessels of the ONH, narrowing and signs of vessels crossing.⁶

3 points: Cup, neuroretinal rim width, haemorrhages, visibility of the retinal nerve fibres as well as zone α and zone β (Jonas).^{1,3–5}

All the pictures of the ONH in the glaucoma stages I–III were shown to 22 observers of different training grades. There were 12 residents (group 1) of the Department of Ophthalmology of the University

Table 1 Patient characteristics: right or left eye, optic disc area, neuroretinal rim area, *c/d* ratio, area of zone α and β , age and stage of disc atrophy (gold standard)

No.	Eye	Optic disc area in (mm ²)	Neuroretinal rim area (mm ²)	C/D ratio	Zone α in mm ²	Zone β in mm ²	Age	Stage
1	Right	3.06	1.96	0.35	1.47	1.4	32	I
2	Left	1.78	0.7	0.61	0.71	0	68	I
3	Left	1.72	1.05	0.39	0.83	0.47	52	I
4	Right	4.12	1.32	0.68	0.83	0	52	I
5	Right	2.81	0.76	0.73	1.67	0.25	62	II
6	Right	2.99	1.32	0.56	0	0.61	70	II
7	Right	3.42	1.15	0.66	0.6	0	62	II
8	Left	3.53	1.08	0.3	0	0	65	II
9	Left	2.48	0.38	0.88	0.88	0	59	III
10	Left	3.11	0.84	0.72	0.64	0	58	III
11	Right	2.36	0.27	0.87	1.24	0.39	60	III
12	Left	2.30	0.27	0.90	1.53	0	64	III

Table 2 Questionnaire

Date:					
Observer:					
Picture no.:					
(1) Area of disc (disc area):	(in mm ²):				
(2) Form of papilla (discform):	Round	Oval	Oblique		
(3) Neuroretinal rim width:	Biggest (NRRStick):	Thinnest (NRRSthin):			
Visibility (visNRRS):	0	+1	+2	+3	(Bad-good)
(4) Depth of cup (cup):	Low	Middle	Deep		
(5) Age (a):	10–20	20–40	40–60	>60	
(6) Cup/disc ratio (c/d):	horizontal:	(0.1–1.0)			
(7) Chorio-pigmentepithelial retinal zone of atrophy:					
Zone a (Zone a):	Small	Middle	Big		
Visibility (visZo a):	0	+1	+2	+3	(Bad-good)
Zone b (Zone b):	Small	Middle	Big		
Visibility (visZo b):	0	+1	+2	+3	(Bad-good)
(8) Retinal vessels of ONH:					
Narrowing (narr):	Thin	Middle	Thick		
Haemorrhages (hem):	Yes	No	Crossing signs (cross):	Yes	No
Hypertension (hypert):	Yes	No	narrowing (narr):	Big	low
(9) Visibility RNF (RNF):	Bad-good:	0	+1	+2	+3
(10) Pores of Lamina cribrosa (visLc):	Small-big:	0	+1	+2	+3
(11) Stage (Jonas):					

Erlangen and 10 ophthalmologists in private practice in the area of Erlangen (group 2).

Before performing the test, the observers' stereoacuity was evaluated using the Random Dot Test (Stereo Optical Co Inc, Chicago, USA). In this test, subjects wore a polarizing spectacle to separate two superimposed polarised monocular images. In our study, a good degree of stereopsis was selected up to 50 s of arc.

All pictures, 2D or 3D, were shown on an EIZO-Computer monitor (distance: approximate 1 m) in a darkened room. The evaluation of the 3D pictures was made with LC shutter glasses type ELSA. The observers were shown 12 pictures that had to be evaluated in 2D, as well as in 3D. That means that they had to comment twice on 12 images each. The evaluation was divided into two courses. For the residents, there was at least a period of 1 week between the evaluations. The ophthalmologists evaluated both courses on the same day in the same chronological order (Table 3).

The questionnaires were worked out in an Excel data file and converted into the statistic program SPSS 12.0. For all variables, descriptive analysis and determination of agreement refers to 264 measurements (22 subjects and 12 optic discs each). Descriptive analysis included means

and standard deviations. Agreement for continuous variables was determined by using the intraclass correlation coefficient, for categorical variables using Cohens κ , and for ordinal variables using Spearman's correlation coefficient. For significance testing, values were averaged over all 12 measurements for one subject such that n was equal to 12 for residents and equal to 10 for ophthalmologists. For averaged values, normal assumption could be assumed, thus t -tests for independent samples (comparison between residents and ophthalmologists) and for dependant samples (comparison of 2D *vs* 3D and 2D, 3D *vs* 'gold standard') were performed. The 'gold standard' for the qualitative and semiquantitative parameters was worked out by our glaucoma specialists of the Department of Ophthalmology in Erlangen. The whole group of the observers (W), as well as the separated groups, residents (R) and ophthalmologists (O), were evaluated separately.

Results

ONH size ($P = 0.013$) and cup/disc ratio ($P < 0.001$) were evaluated significantly differently in 2D compared with 3D. Both parameters were measured larger by 3D as

compared with 2D measurements. No significant differences were observed between the gold standard and residents or ophthalmologists for the ONH size, but for the c/d ratio measured in 2D, which was estimated smaller by both groups of observers as compared with the 'gold standard' ($P = 0.047$, $P = 0.052$). Estimations of optic disc size and c/d ratio were not different between residents and ophthalmologists (Table 4).

The spatial parameter rim area ($P < 0.001$) and the parapillary atrophy areas zone α ($P = 0.002$) and zone β ($P = 0.003$) were significantly better visible for 3D as compared with 2D measurements. There were no differences between residents and ophthalmologists (Table 5a and b).

Table 3 Chronological order of the pictures, as presented to the observers

Course 1			Course 2		
Picture	2D/3D	Stage (glaucoma)	Picture	2D/3D	Stage (glaucoma)
Picture 9	2D	III	Picture 2	3D	I
Picture 4	3D	I	Picture 5	2D	II
Picture 2	2D	I	Picture 9	3D	III
Picture 5	3D	II	Picture 12	2D	III
Picture 10	2D	III	Picture 8	3D	II
Picture 11	3D	III	Picture 3	2D	I
Picture 8	2D	II	Picture 1	3D	I
Picture 7	3D	II	Picture 7	2D	II
Picture 1	2D	I	Picture 10	3D	III
Picture 12	3D	III	Picture 4	2D	I
Picture 6	2D	II	Picture 6	3D	II
Picture 3	3D	I	Picture 11	2D	III

Agreement between 2D and 3D classifications was limited with κ -values between 0.34 (hypertension, lowest correlation) and 0.75 (haemorrhage, highest correlation) and Spearman's correlations between 0.37 (width of retinal vessels, degree of cupping) and 0.72 (degree of disc cupping). The weighted score of correct answers shows that classification errors with respect to the 'gold standard' were significantly smaller for 3D measurements as compared with 2D measurements ($P = 0.07$). The residents improved from 18.27 to 19.34 and the ophthalmologists from 17.98 to 19.24 correct answers out of 36 possible ones (Table 7). There were no significant differences between both groups. Significance was observed for the thinnest sector of the neuroretinal rim, the degree of cupping, crossings of vessels, and the visibility of the retinal nerve fibres. However, the stage of glaucomatous ONH atrophy, the existence of hypertension, and the parapillary zone β were classified with smaller error by 2D as compared with 3D evaluation ($P = 0.061$, $P = 0.73$, $P = 0.19$, not significant; for all results Table 6).

Discussion

In our study, we chose a computer-assisted time-multiplexing system using liquid shutter-glass technology, because it can easily be integrated in an ordinary ophthalmologist's cabinet. This system provides a high-resolution power of 3D pictures with real colour presentation which guarantees nearness to reality for a correct clinical evaluation of the glaucomatous disc.

The Scanning laser tomography has become a very important and almost universal method appropriate for

Table 4 Optic disc size and the c/d ratio (measured values and absolute differences to the 'gold standard')

Gold standard	2D residents	2D ophthalmologists		3D residents	3D ophthalmologists	
Disc size, 2D vs 3D: $P = 0.013^a$						
2.81 ± 0.69	2.69 ± 0.63	2.92 ± 0.70	$P = 0.20^b$	2.76 ± 0.66	3.02 ± 0.69	$P = 0.13^b$
	$P = 0.24^c$	$P = 0.48^c$		$P = 0.64^c$	$P = 0.16^c$	
	ICC = 0.54	ICC = 0.43		ICC = 0.32	ICC = 0.41	
Disc size, absolute difference to gold standard, 2D vs 3D: $P = 0.49^a$						
—	0.53 ± 0.40	0.64 ± 0.46	$P = 0.08^b$	0.58 ± 0.42	0.62 ± 0.46	$P = 0.34^b$
c/d ratio, measurements, 2D vs 3D: $P < 0.001^a$						
0.64 ± 0.20	0.59 ± 0.19	0.54 ± 0.22	$P = 0.273$	0.66 ± 0.20	0.59 ± 0.22	$P = 0.14^b$
	$P = 0.047^c$	$P = 0.052^c$		$P = 0.20^c$	$P = 0.25^c$	
	ICC = 0.53	ICC = 0.31		ICC = 0.54	ICC = 0.26	
c/d ratio, absolute difference to gold standard, 2D vs 3D: $P = 0.20^a$						
—	0.16 ± 0.14	0.22 ± 0.19	$P = 0.079^b$	0.15 ± 0.13	0.21 ± 0.17	$P = 0.07^b$

Entries: mean $\pm$ SD, ICC = intraclass correlation.

^aComparison between 2D and 3D measurements, all 22 subjects.

^bComparison between residents and ophthalmologists.

^cComparison between 2D or 3D measurements and gold standard, separately for residents and ophthalmologists.

All P-values refer to *t*-tests with *n* equal to the number of subjects (cf. Methods and patients).

glaucoma diagnosis. But it shows the pictures only in a pseudo -3D image, which may lead to an over proportional representation of the cupping with nonreal, coding colours. The resolution power, compared with slide film, is rather low because of its small resolution (e.g. 256×256 pixels).⁷

The Discam stereo fundus photcamera (Discam, Marcher enterprises, UK) only takes pictures in monochromatic quality and it is also rather expensive.^{8,9}

In our study, the quantitative parameters ONH size and *c/d* ratio have been evaluated significantly differently on 3D images. The ONH size was measured

larger by 3D as compared with 2D measurements, but there were no significant differences either between the 'gold standard' compared with the answers of both groups or between the evaluations of residents versus ophthalmologists. Interesting is that the residents were much better as ophthalmologists in their estimations of the disc size. In 3D, the mean value only varied 0.05 mm^2 from the real value. The explication may be found in the fact that during his/her training at a university hospital, residents are continuously asked to estimate the size of the ONH in patient demonstrations. The ophthalmologists made a better evaluation in 2D, because they always overestimated the papilla size so that it was worse interpreted in 3D.

The evaluation of the *c/d* ratio showed a better result in 3D for all of the groups, because there was a significant difference between the measurements in 2D compared with the gold standard. The *c/d*-ratio was estimated as much too small of both groups on the 2D pictures. Therefore, the spatial image helped to get a better result. The estimations of the residents were very good on stereopictures. In 3D, the mean estimation only varied 0.02 mm^2 from the real value. But also the ophthalmologists improved their estimation of the *c/d* ratio in 3D. These results are in accordance with the study by Li *et al.*, which showed that the evaluation of the *c/d* ratio lead to excellent results by using stereoscopic images.²

The spatial parameters rim area and parapapillary atrophy, which are very important for glaucoma diagnosis, were significantly better visible on stereoscopic pictures as compared with 2D measurements (Table 5a and b). There were no differences between residents and ophthalmologists which show that both groups were more satisfied to evaluate those spatial parameters on a stereoscopic picture and that perhaps it would help to pose a good diagnosis in their daily work.

The evaluation of the stage of glaucomatous ONH, atrophy according to Jonas, of the whole group of observers showed better results in 2D ($P = 0.061$, not significant).³ Residents with limited experience often have problems in the daily clinical visualisation of the papilla in 3D. In the

Table 5a Evaluation of rim area and parapapillary atrophy (zone alpha, zone beta)

Rim area	3D visibility	0	1	2	3	Total
2D visibility						
0		5	7	5	3	20
1		0	25	50	10	85
2		1	13	49	41	104
3		2	1	5	47	55
Total		8	46	109	101	264
Alpha zone	3D visibility					
2D visibility						
0		7	5	1	3	16
1		1	47	46	9	103
2		1	11	58	30	100
3		2	3	12	28	45
Total		11	66	117	70	264
Beta zone	3D visibility					
2D visibility						
0		16	3	4	2	25
1		3	44	43	14	104
2		0	18	56	20	94
3		2	2	11	26	41
Total		21	67	114	62	264

Higher scores refer to better visibility; the upper right part of each subtable refers to better visibility of 3D measurements.

Table 5b

	2D residents	2D ophthalmologists		3D residents	3D ophthalmologists	
Rim area, $P < 0.001^a$	1.69 ± 0.59	1.79 ± 0.48	$P = 0.66^b$	2.19 ± 0.56	2.10 ± 0.55	$P = 0.72^b$
Zone α , $P = 0.002^a$	1.76 ± 0.59	1.53 ± 0.44	$P = 0.32^b$	1.97 ± 0.62	1.88 ± 0.58	$P = 0.73^b$
Zone β , $P = 0.003^a$	1.67 ± 0.64	1.45 ± 0.48	$P = 0.37^b$	1.83 ± 0.63	1.82 ± 0.60	$P = 0.97^b$

Entries: mean $\pm$ SD.

^aComparison between 2D and 3D measurements, all 22 subjects.

^bComparison between residents and ophthalmologists, values are averaged over 12 optic disc evaluation for each subject.

Table 6 Qualitative and semiquantitative evaluations of the optic disc (absolute errors compared to the gold standard)

	2D		3D	
	Residents	Ophthalmologists	Residents	Ophthalmologists
Papform (3 categories) $P = 0.18$, $\kappa = 0.37$	0.39 ± 0.49	0.39 ± 0.49	0.33 ± 0.47	0.34 ± 0.48
Nrr thickest (4 categories) $P = 0.76$, $\kappa = 0.40$	0.30 ± 0.46	0.28 ± 0.45	0.29 ± 0.46	0.27 ± 0.44
Nrr thinnest (4 categories) $P = 0.04$, $\kappa = 0.45$	0.28 ± 0.45	0.82 ± 0.39	0.73 ± 0.45	0.76 ± 0.43
Excavation (3 degrees) $P < 0.001$, $\rho = 0.37$	0.68 ± 0.65	0.73 ± 0.66	0.50 ± 0.58	0.45 ± 0.59
Age (4 degrees) $P = 0.85$, $\rho = 0.52$	0.92 ± 0.84	0.89 ± 0.82	0.92 ± 0.82	0.87 ± 0.73
Alpha zone (3 degrees) $P = 0.77$, $\rho = 0.54$	0.78 ± 0.71	0.89 ± 0.75	0.81 ± 0.68	0.84 ± 0.74
Beta zone ^a (3 degrees) $P = 0.19$, $\rho = 0.57$	0.57 ± 0.67	0.48 ± 0.66	0.62 ± 0.68	0.52 ± 0.62
Vessels size (3 degrees) $P = 0.77$, $\rho = 0.37$	0.49 ± 0.54	0.44 ± 0.55	0.49 ± 0.54	0.47 ± 0.55
Haemorrhage yes/no $P = 0.41$, $\kappa = 0.75$	0.06 ± 0.24	0.08 ± 0.26	0.04 ± 0.20	0.07 ± 0.25
Crossings yes/no $P = 0.03$, $\kappa = 0.42$	0.28 ± 0.45	0.30 ± 0.46	0.22 ± 0.41	0.26 ± 0.44
Hypertension ^a yes/no $P = 0.73$, $\kappa = 0.34$	0.44 ± 0.50	0.29 ± 0.46	0.44 ± 0.50	0.32 ± 0.47
Narrowing yes/no $P = 0.14$, $\kappa = 0.43$	0.38 ± 0.49	0.39 ± 0.51	0.29 ± 0.46	0.39 ± 0.51
RNF (4 degrees) $P = 0.005$, $\rho = 0.55$	0.93 ± 0.76	1.04 ± 0.78	0.65 ± 0.67	0.72 ± 0.64
Lamina cribrosa (4 degrees) $P = 0.15$, $\rho = 0.58$	0.80 ± 0.74	0.68 ± 0.71	0.67 ± 0.67	0.57 ± 0.71
Stage ^a (6 degrees) $P = 0.061$, $\rho = 0.72$	0.75 ± 0.73	0.88 ± 0.83	0.86 ± 0.64	0.98 ± 0.87

For ordinal variables the absolute difference of categories was used, for categorical variables only true/false classification was used.

^aFor these variables, the errors of 2D were smaller than the errors of 3D measurements, for all other variables the errors of 2D were larger than those of 3D measurements, P -values refer to the comparison of 2D vs 3D errors. κ = Cohens kappa for categorical variables, ρ = Spearman correlation for ordinal variables. P -values are determined for averaged values over 12 optic-disc evaluations for each subject, κ and ρ was determined based on 264 single classifications

beginning, on using the slit lamp, although it is used binocular, one eye dominates so that the image received is only 2D. The evaluation of the glaucomatous stage of the ONH atrophy is better in 2D because it is similar to their daily work. For all the other qualitative and semiquantitative parameters, 3D visualization allowed a better evaluation but not always a significant one.

The retinal nerve fibres were evaluated significantly better in 3D ($P = 0.005$) in both groups. Experience in 3D visualization is not of great importance for these parameters. Also beginners can give a more precise estimation in 3D of spatial parameters like depth of cup and features like vessels 'kinking' in the depth. Therefore, the degree of excavation and crossings of vessels have shown a significant better result in 3D ($P < 0.001$ and $P = 0.03$, respectively). The estimation of cup depth on fundus pictures with 3D may be important, as it has been shown in the past that there was only a marginal level of agreement with HRT cup-depth measurements.⁷

The whole group gave a better evaluation of the neuroretinal rim in 3D vs 2D, but the value was only significant for the thinnest quadrant of the neuroretinal rim ($P = 0.04$).

To examine how the estimation of the same parameter agreed from 2D to 3D, we measured the correlation between the answers. Agreement between 2D and 3D classifications was limited with κ values between 0.34 (hypertension, lowest correlation) and 0.75 (haemorrhage, highest correlation) and Spearman correlations between 0.37 (size of vessels, degree of

excavation) and 0.72 (stage of optic disc atrophy according to Jonas).

The correlation between the observers' answers in 2D and 3D was moderate, which shows that the evaluation depended on the field of activity (hospital of university, urban hospital, cabinet) and on the personal experience.

The parameter that showed the best correlation was the visibility of bleedings or not (haemorrhage $\kappa = 0.75$). Also the stage of glaucomatous optic disc atrophy (according to Jonas) showed a high correlation ($\kappa = 0.72$), because nearly all the observers were educated in the same university department of ophthalmology. The lowest correlations occurred with parameters that depend intensively on the subjective estimation of the observer: the visibility of neuroretinal rim, the excavation and crossings. Those parameters give a more 'spatial' image in 3D and are perhaps easier to identify than on a 2D image, because these parameters had been significantly better evaluated in 3D. There was no significant difference between the residents and the ophthalmologists.

Parameters like arterial hypertension and age of the patient were examined for interest. There were age-correlated signs. An attached posterior vitreous membrane was a sign that it was a young patient, but if there was sclerosis in the retinal vessels it was a sign for a higher age of the patient. The correlation of the answers also varied strongly, because the observers are not used to evaluating the age of the patient on an ONH picture. There was no significant difference between the residents and the ophthalmologists.

Table 7 Weighted score for quality of disc assessment

	2D		3D	
	Residents	Ophthalmologists	Residents	Ophthalmologists
2D vs 3D:				
$P = 0.007$ (all subjects)	18.27 ± 2.34	17.98 ± 1.73	19.34 ± 3.14	19.24 ± 2.28
$P = 0.12$ (residents)	Residents vs ophthalmologists: $P = 0.75$		Residents vs ophthalmologists: $P = 0.94$	
$P = 0.018$ (ophthalmologists)				

P -values are determined for averaged values over 12 optic disc evaluations for each subject.

Spatial parameters were significantly better rated on stereoscopic images. The observers had to evaluate the neuroretinal rim width, which means the distance of the ONH to the scleral–Elschnig ring. In this study, the neuroretinal rim width was significantly better evaluated in 3D (significance for the thinnest quadrant of the neuroretinal rim). The result is the same as in a study made in 1998 and in a second one in 2000 in Perth by CJ Barry and R Eikelboom at the Lions Eye Institute: Glaucomatous changes of the neuroretinal rim could be better imagined and evaluated with 3D techniques.^{10,11}

Counting the correct answers, there was a significant difference between both methods. The evaluation was significantly better in 3D ($P = 0.007$). There was no significant difference between the groups. Both, residents and ophthalmologists, improved with 3D pictures and got a higher score of correct answers (Table 7). An interesting question would be if someone can improve this result by training or if it is a weakness of the 3D view.

Normally, a better evaluation of the pictures with a high grade of glaucomatous atrophy, than with grades of the beginning pathology was expected. But the study could not find a different quality of diagnosis between early glaucomatous optic disc atrophy and a progressed ONH atrophy stage III.

In conclusion, using a computer-assisted time multiplexing system, all the observers, residents and ophthalmologists, achieved a significantly better evaluation of the ONH with 3D than with 2D pictures in glaucoma diagnosis. The only exceptions were the estimation of the stage of glaucomatous optic disc atrophy, the existence of arterial hypertension signs and parapapillary atrophy zone β , which were better evaluated in 2D, but not significant.

Important parameters in the diagnosis of the glaucomatous ONH atrophy like the c/d ratio, the depth of the excavation and the neuroretinal rim width were significantly better evaluated on the stereoscopic images of all groups of observers. The visibility of spatial parameters like the parapapillary atrophy and the rim area were also better in stereo, which was confirmed of both groups.

These results may provide a new visualization method in the diagnosis of glaucomatous ONH atrophy into the ophthalmologic clinical routine, as the correct ONH evaluation and detection of morphological changes play an important role in glaucoma treatment. A possible future scenario would be the ability to view and exchange high-quality, computer-storable ONH images in 3D via internet with the referring hospital to discuss glaucoma patients.

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