# CHAPTER 2

## *Motion artifacts in scanning laser polarimetry*

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**Abstract**

**Purpose** The GDx (Laser Diagnostic Technologies, San Diego, CA) is a scanning laser polarimeter that measures retardation to assess retinal nerve fiber layer thickness *in vivo*. Eye movements during image acquisition may result in motion artifacts in the GDx image. The aim of this study was to investigate the effect of motion artifacts on the retardation values, and to illustrate how motion artifacts can be identified.

**Design** Observational case series.

**Participants** Thirty-two normal subjects and 28 glaucoma patients participated.

**Methods** We imaged all 60 subjects with the GDx. Images with identified motion artifacts were compared with images without motion artifacts from the same eye and the same session. In 25 cases, the artifact was identified in the superior segment only, and the effect on the superior maximum parameter was calculated. In 26 cases, the artifact was observed in the inferior segment only, and the effect on the inferior maximum parameter was calculated. In 9 cases, the artifact was observed superiorly and inferiorly, and the effect on both parameters was calculated. In all 60 cases, the effect on the Number (a summary parameter) was calculated. We also analyzed the groups of glaucoma patients and normal subjects separately.

**Main outcome measures** Superior maximum parameter, inferior maximum parameter, the Number parameter.

**Results** In general, the identified motion artifacts led to an increase in retardation, reflected by an increase in the superior maximum and inferior maximum parameter by 5.9μ and 3.4μ respectively ($P<0.001$). The Number decreased by 3.4 with motion artifacts ($P=0.001$). The variability of this effect was large. In one case, the motion artifact increased retardation by as much as 28.6μ. The effect of motion artifacts was higher in glaucoma patients than in normal subjects.

**Conclusions** The identified motion artifacts generally increase retardation values. This increase, however, is highly variable. Therefore, images with such motion artifacts should be viewed with caution, or excluded from analysis.

## Introduction

The GDx (Laser Diagnostic Technologies, San Diego, CA) is a scanning laser polarimeter that measures retardation originating from the retina, attributed to the birefringent properties of the nerve fiber layer (NFL). Retardation values are linearly correlated with NFL thickness, as has been shown in a monkey model.[1] The retardation map produced by the instrument therefore provides a measure of retinal NFL thickness. The GDx also calculates 14 parameters that may be used to dis-

criminate normal subjects from glaucoma patients.[2-4] A more detailed description of the GDx can be found elsewhere. [5-7]

In our experience, motion artifacts are commonly seen in a GDx image when the eye moved during image acquisition. They can affect the amount of measured retardation, and thus make the GDx data less reliable, or sometimes useless. Although the GDx software routinely checks the image quality, it does not detect motion artifacts. It was the aim of this study to examine the effect of motion artifacts on the retardation values in normal subjects and glaucoma patients, to demonstrate the importance of recognizing them, and to illustrate how they can be identified.

## Methods

**Subjects and measurement procedures** Participating in a long-term follow-up trial, 350 subjects made their six-monthly visit, to be imaged with the GDx by one of three experienced operators. The subjects were imaged until at least three images per eye met all of the following four quality criteria: optic nerve head well-centered, just image illumination, good focus and no motion artifacts throughout the image. Just image illumination entails that the image is evenly illuminated and neither too bright, nor too dark. Patients became eligible for the current study, if their images also contained at least one image with a motion artifact. The image should otherwise be of high quality. Such an image with motion artifacts would have normally been deleted, but was now kept and compared with the first of the high-quality images. Only one image with motion artifacts was used per subject. When the arbitrarily determined sample size of 60 subjects was reached, the inclusion for this study was terminated.

Of the 60 subjects, 32 were healthy volunteers (mean age 56.5 years) who had met their original inclusion criteria of Caucasian ethnic origin, age between 20-80 years, intraocular pressure <=21 mm Hg, a normal appearance of the optic nerve head and normal visual fields (Humphrey Field Analyzer 24-2 full threshold program). They did not have diabetes, hypertension requiring medical treatment, any significant ocular history, a vertical cup/disc ratio of 0.6 or higher, nor an asymmetry of greater than 0.2 vertical cup/disc ratio between the two eyes. The other 28 subjects were glaucoma patients (mean age 66.9 years) who had met their original inclusion criteria of: Caucasian ethnic origin, age between 20-80 and a diagnosis of glaucoma (on the basis of reliable and repeated glaucomatous visual field abnormalities with matching optic disc abnormalities) established by one of our three glaucoma specialists. Exclusion criteria were diabetes, systemic hypertension requiring medical treatment, any ocular history or any ocular surgery. Refractive error was not among the selection criteria as long as it didn't compromise focussing.

The operators who selected the subjects for this trial were unaware of the outcome of the NFL thickness parameters. During all measurements, we saw to it that patients had their heads as upright as possible. Pupils were undilated and ambient lights were left on. IRB/Ethics Committee approval was obtained for this study and written informed consent was obtained from all participants at enrolment in the follow-up trial.

**Parameters** The GDx software calculates several parameters from the retardation image. The superior maximum (smax) parameter is the average value of the 1500 pixels with the highest retardation in the superior segment. The inferior maximum (imax) parameter is defined likewise for the inferior segment. Retardation values in degrees are converted to microns by multiplying them by 7.4, as one degree of retardation has been shown to correspond to 7.4μ of nerve fiber layer thickness in a monkey model.[1] The Number is a summary parameter ranging from 0-100 that is calculated from existing parameters by a proprietary algorithm. A high value indicates a high probability of glaucoma, but not necessarily an advanced stage of the disease. For clarity, we limited our quantitative analysis of the effects of motion artifacts to only these three parameters.

**Motion artifacts & description of examples** Motion artifacts occur when the eye of the patient moves during image acquisition. The eye movements can be optionally seen on the GDx monitor when the individual scans (approx. 20) are displayed in quick succession (the so-called "movie"). The hallmark of motion artifacts is sharp, colored lines along the blood vessels in the retardation image. The lines are not present on images when the eye was kept still during scanning. When the blood vessels are located in an area that appears red on the retardation image, motion artifacts usually appear as bright yellow lines. When the blood vessels are located on a blue background, the motion artifacts usually appear as red lines. In addition, the overall retardation in the area of the motion artifacts tends to be higher as compared to an image without motion artifacts. Figure 2-1 (p.103) shows four examples of images with motion artifacts. The eyes in example #1 and #2 are healthy; the eyes in example #3 and #4 are glaucomatous. Going from left to right, we have presented the reflectance image, the retardation image containing motion artifacts, and the retardation image of the same eye without motion artifacts. The reflectance image of the scan without motion artifacts is not shown to save space. Several motion artifacts have been marked with an arrow.

In example #1, there are a few motion artifacts in the superior segment. Note the yellow lines along the blood vessels in the middle image, and their absence in the right image. The smax parameter was 82μ in the image with motion artifacts, and 74μ in the image without motion artifacts.

In example #2, quite a large motion artifact can be seen superiorly (note the bright yellow line) in addition to a smaller motion artifact more to the right. The smax parameter was 100μ in the image with motion artifacts and 93μ in the image without motion artifacts. Also, two motion artifacts may be identified inferiorly. The imax was 98μ in the image with the identified motion artifacts and 87μ in the image without motion artifacts. Note that with the motion artifacts the retardation in the entire superior segment has increased visibly in the image.

Example #3 shows large motion artifacts inferiorly, and some small motion artifacts superiorly. The imax is 97μ in the image with motion artifacts and 89μ in the image without motion artifacts. By contrast, the smax is lower in the image with motion artifacts than in the image without motion artifacts (70μ and 73μ respectively). In our experience, this is a rare finding.

Example #4 shows how large the effect of motion artifacts can be. In the image with motion artifacts, the smax was 79μ and the imax was 70μ. In the image without motion artifacts the smax was 50μ and the imax was 57μ. Due to all the red color, which is probably entirely caused by artifact, the image with motion artifacts may not seem very abnormal to the inexperienced user. However, the image without artifacts shows an eye with retardation levels that are clearly subnormal, indicating advanced glaucoma. This is also illustrated by the visual field of this eye in fig 2-2 (p.104).

Finally, in images with motion artifacts, a black rectangle may be observed at the edge of the image. This can be observed at the left side of example #2 and #3, and on the right side of example #4. During scanning, approximately 20 separate scans are acquired at different angles of polarization. All 20 scans are required to construct the displayed retardation image. Obviously, all 20 scans need to be aligned. Only those pixels that overlap in all 20 scans, are finally displayed; all missing pixels will be presented in black. With eye movements, missing pixels are most likely to occur at the edges.

**Statistical methods** Since all patients served as their own controls, a relatively low sample size of 60 subjects was thought to be sufficient at the start of the trial. A special version of the GDx 2.0.09 software enabled us to automatically translate all parameters into a statistical software package (SPSS version 9.0, SPSS Inc., Chicago, IL). A paired Student's t-test, with the level of statistical significance set at $\alpha = 0.05$ was used to compare all images with motion artifacts to those without.

First, data of all 60 images were pooled and analyzed together. If a motion artifact was identified superiorly, the smax parameter was calculated. In case of an inferior motion artifact, we calculated the imax parameter. If a motion artifact was identified superiorly and inferiorly, both parameters were calculated. Irrespective of where the motion artifact was, the Number was calculated. We now compared the parameters of images with motion artifacts to those in images without motion artifacts. Then, the same calculations were applied to the normal eyes and the glaucomatous eyes separately.

Finally, we counted the number of healthy subjects and the number of glaucoma patients in which the smax parameter had been affected beyond the limits of agreement as calculated in a separate study population.[8] The limits of agreement for the smax was found to be 7.2μ for normals and 8.7μ for glaucoma patients.[9] The limits of agreement indicate how much a particular parameter would have to change to fall outside the ranges of variability of a repeated measurement, and thus become clinically significant. Motion artifacts that affect a parameter beyond these limits could potentially interfere with a clinical decision.

**Results**

In general, motion artifacts significantly increased the retardation. This was clearly reflected by the smax and imax parameter, but also by the Number (table 2-1). In all subjects, motion artifacts increased the superior maximum (smax) parameter by, on average, 5.9μ ($p<0.001$), corresponding to 7.4%. For the inferior maximum (imax) parameter this increase was 3.4μ ($p<0.001$; 3.9%). These differences showed a large

variability. For example, the range of the mean difference in the smax parameter was from –6.0μ to +28.6μ, with a standard deviation of 7.1μ. In three cases, the retardation in images with motion artifacts was lower than in images without motion artifacts. On the other hand, the difference in the smax parameter could be as high as 28.6μ, which corresponded to 58%.
The increase in retardation caused by motion artifacts was higher in glaucoma patients than in normals. For example, the mean difference in the smax parameter was 7.7μ in glaucoma patients and 4.4μ in normals. The effect of motion artifacts was again highly variable, as illustrated by the high standard deviation values.

In normals, the change in The Number caused by motion artifacts was small and statistically not significant (p=0.31). In glaucoma, the Number generally decreased with motion artifacts by, on average, 6.4 (p=0.001). This decrease, however, could be as high as 33.

To understand the results in terms of limits of agreement, we calculated the number of subjects who had an increase in the smax beyond the limits of agreement. These limits are 7.2μ for healthy subjects, and 8.7μ for glaucoma patients. This was true for 5 out of 32 (i.e. 15.6%) healthy subjects, and for 5 out of 28 (i.e. 17.9%) glaucoma patients.

## Discussion

This is the first study that addresses motion artifacts in GDx scans. We have demonstrated that they generally increase retardation values, especially in glaucoma patients. Also, the artifactual retardation may vary considerably, thereby unpredictably affecting the measurements. We therefore think that scans with identified motion artifacts should be disregarded for further analysis. Looking for motion artifacts should therefore occur with the patient still by the GDx, to allow for rescanning the eye, if required.

As a result of the artifactual increase in retardation, glaucomatous eyes may be falsely classified as normal. This will likely impair the sensitivity of this technology for detecting glaucoma. Also, the follow-up of individual eyes will be less sensitive for detecting real change over time because artifactually high retardation measurements may mask true progression. In addition, baseline images with motion artifacts may, at a later stage, be the cause of a false positive appearance of progressive NFL thinning. We have demonstrated that, due to motion artifacts, 15.6% of normals and 17.9% of glaucoma patients showed an increase in retardation beyond its limits of agreement.

We have demonstrated how to identify motion artifacts, which is, in most cases, fairly easy. Only occasionally can some doubt remain whether yellow lines along blood vessels reflect a thicker part of the NFL, or whether they are artifactual. In these situations, the software can play back a movie of the optic nerve head that was recorded during the 0.7 seconds of image acquisition, showing whether the eye was kept still during imaging or not. Also, making several scans in a row can be of help, since the difference between motion artifacts and no motion artifacts can easily be seen in subsequent images. Since the GDx image quality check software does not detect motion artifacts, a ‘passed’ overall image quality score does not mean the image is free of motion artifacts. A software utility that can detect motion artifacts would be very useful, especially for the beginning user.

In conclusion, motion artifacts may cause spuriously higher retardation in scanning laser polarimetry. As a result the sensitivity for detecting glaucoma is likely to be adversely affected. In addition, follow-up will probably be less useful if images with motion artifacts are not identified and disregarded, especially at base line imaging. Fortunately, motion artifacts are usually easily identified and should prove no limitation to the experienced clinician working with the GDx.

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**Table 2-1.**
The effect of motion artifacts on three different GDx parameters.

| Parameters | n | with MA | without MA | mean difference | SD of difference | range of difference | 95% CI of difference | p-value |
|---|---|---|---|---|---|---|---|---|
| **All subjects** | **60** | | | | | | | |
| Smax (μ) | 34 | 85.4 | 79.5 | 5.9 (7.4%) | 7.1 | -6.0 ; +28.6 | +3.4 ; +8.3 | < 0.001 |
| Imax (μ) | 35 | 91.5 | 88.1 | 3.4 (3.9%) | 3.4 | -1.6 ; +12.4 | +2.3 ; +4.7 | < 0.001 |
| The Number | 60 | 30.2 | 33.6 | -3.4 (10.1%) | 7.4 | -33 ; +11 | -5.3 ; -1.5 | 0.001 |
| **Normals** | **32** | | | | | | | |
| Smax (μ) | 19 | 93.1 | 88.7 | 4.4 (5.0%) | 7.3 | -6.0 ; +23.2 | +0.8 ; +7.9 | 0.018 |
| Imax (μ) | 20 | 97.1 | 94.3 | 2.8 (3.0%) | 3.3 | -1.6 ; +10.6 | +1.2 ; +4.3 | 0.001 |
| The Number | 32 | 15.0 | 15.7 | -0.7 (4.5%) | 3.7 | -11 ; +11 | -2.0 ; +0.7 | 0.31 |
| **Glaucoma** | **28** | | | | | | | |
| Smax (μ) | 15 | 75.7 | 67.9 | 7.7 (11.3%) | 6.6 | +1.2 ; +28.6 | + 4.1 ; +11.4 | < 0.001 |
| Imax (μ) | 15 | 84.1 | 79.7 | 4.4 (5.5%) | 3.6 | -0.7 ; +12.4 | + 2.4 ; +6.4 | < 0.001 |
| The Number | 28 | 47.6 | 54.1 | -6.4 (11.8%) | 9.1 | -33 ; +2 | -10.0 ; -2.9 | 0.001 |

Data of all subjects were pooled and mean values of three different parameters are given with motion artifacts (MA) and without motion artifacts. The mean difference between the two is expressed in microns and as a percentage of the value without motion artifacts. For this difference the standard deviation (SD), the range, the 95% confidence interval (CI) and the p-values are given. Also, all values are presented again for the group of glaucoma patients and the group of normal subjects separately.

## References


1. Weinreb RN, Dreher AW, Coleman A, et al. Histopathologic validation of Fourier-ellipsometry measurements of retinal nerve fiber layer thickness. Arch Ophthalmol 1990;108:557-60.
2. Tjon-Fo-Sang MJ, Lemij HG. The sensitivity and specificity of nerve fiber layer measurements in glaucoma as determined with scanning laser polarimetry. Am J Ophthalmol 1997;123:62-9.
3. Weinreb RN, Zangwill L, Berry CC, et al. Detection of glaucoma with scanning laser polarimetry. Arch Ophthalmol 1998;116:1583-9.
4. Choplin NT, Lundy DC, Dreher AW. Differentiating patients with glaucoma from glaucoma suspects and normal subjects by nerve fiber layer assessment with scanning laser polarimetry. Ophthalmology 1998;105:2068-76.
5. Dreher AW, Reiter K. Retinal laser ellipsometry: a new method for measuring the retinal nerve fiber layer thickness distribution. Clin Vis Sci 1992;7:481-8.
6. Tjon-Fo-Sang MJ, de Vries J, Lemij HG. Measurement by nerve fiber analyzer of retinal nerve fiber layer thickness in normal subjects and patients with ocular hypertension. Am J Ophthalmol 1996;122:220-7.
7. Weinreb RN, Shakiba S, Zangwill L. Scanning laser polarimetry to measure the nerve fiber layer of normal and glaucomatous eyes. Am J Ophthalmol 1995;119:627-36.
8. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;307-10.
9. Colen TP, Tjon-Fo-sang MJ, Mulder PG, Lemij HG. Reproducibility of measurements with the nerve fiber analyzer (NFA/GDx). J Glaucoma 2000;9:363-70.