Graefe's Arch Clin Exp Ophthalmol (1993) 231:687–691

Graefe's Archive
for Clinical and Experimental
Ophthalmology

Minimum views required to characterize cataracts when using the Scheimpflug camera

Kayoko Kashima[1], **Michael Unser**[2], **Manuel B. Datiles**[1], **Benes L. Trus**[3], **Paul A. Edwards**[1]

[1] Cataract and Corneal Diseases Section, OG&CS Branch, National Eye Institute, National Institutes of Health, Bethesda, Maryland, USA
[2] Biomedical Engineering and Instrumentation Program National Institutes of Health, Bethesda, Maryland, USA
[3] Computer Systems Laboratory, Division of Computer Research and Technology, National Institutes of Health, Bethesda, Maryland, USA

Received: 11 August 1992 / Accepted: 15 March 1993

Abstract. We performed Scheimpflug slit lamp photography and computerized image analysis on 20 normal and 25 cataractous lenses using 18 slit images for each lens taken 10° apart. The data gathered from the normals served as the reference to estimate the accuracy of representation of the cataracts by the least number of views (18 and less) using a Fourier interpolative algorithm. Using the error obtained with one view for the normals, our study suggests that the minimum number of views necessary for adequate characterization is two for cortical cataracts, two for nuclear cataracts, and six for posterior subcapsular cataracts. This information will be useful in longitudinal studies of cataracts, since most researchers presently use only one view, which may be adequate for normals but not for cataractous lenses. We found the Fourier interpolative algorithm useful in estimating the minimum views required for the current method of analyzing Scheimpflug images, and it can be easily applied to other similar images.

Introduction

With the development of possible anti-cataract drugs, objective, sensitive, and standardized methods of monitoring cataracts are of paramount importance for long-term clinical trials. Many previous reports [1, 3, 5–7] have shown the possible usefulness of the Topcon Scheimpflug camera for such clinical trials and for various studies on the lens and cataracts. Although this is not the only method to document and monitor cataracts, it has been shown to be useful and the results reproducible, especially for nuclear cataracts and for opacities located centrally. Peripheral cortical changes, which do not contribute to loss of vision related ro cataracts, are more appropriately followed by other methods, such as retroillumination photography [8].

In actual practice, especially for long-term studies such as natural history studies or clinical trials of anti-cataract drugs, there is a need to determine the minimum number of views necessary with this technique, for various reasons. If too many shots are taken, the flash and the viewing light may bother the patient, leading to loss of fixation, less cooperation with the procedure, and decreased reliability of results. In addition, one is saddled with an unnecessarily large amount of data to store and analyze. On the other hand, researchers may use only one view (usually the 90°) to study Scheimpflug images, which may be adequate for normal lenses but not for cataractous lenses.

Since each Scheimpflug slit photograph can document only the portion of the lens in the slit, we wanted to determine how many photographs (views) are needed to characterize a cataract adequately and efficiently using this instrument. Some researchers recommend, based on experience, that four views be taken, 45 deg apart [7]. Others recommend one view at 90° [2]. However, it appeared to us that while these suggestions are based on years of experience, a sound statistical analysis would be useful to validate or update the suggested minimum number of views which should be taken with the Scheimpflug camera routinely.

Materials and methods

All subjects were part of a research protocol approved by theNational Eye Institute Intramural Research Board and gave informed consent.

Using the Topcon SL-45 slit lamp camera we obtained Scheimpflug photographs of 20 normal eyes with clear lenses and 25 eyes with cataracts – 7 nuclear, 8 cortical, and 10 posterior subcapsular – for a total of 45 eyes. Informed consent was obtained from all normal volunteers and cataractous patients. Lenses with congenital nuclear dots were excluded from this study. The pupils were dilated maximally using three doses each of 1% mydriacyl and 2.5% neosynephrine eye drops. One of the authors (MD) performed standard ophthalmological examinations on these normal volunteers and cataractous patients and classified the lens changes based on slit lamp biomicroscopy findings. The photographs were carefully

---

Correspondence to: Manuel Datiles, NIH–NEI, 9000 Rockville Pike Bldg. 10, Rm. 10N226, Bethesda, MD 20892, USA

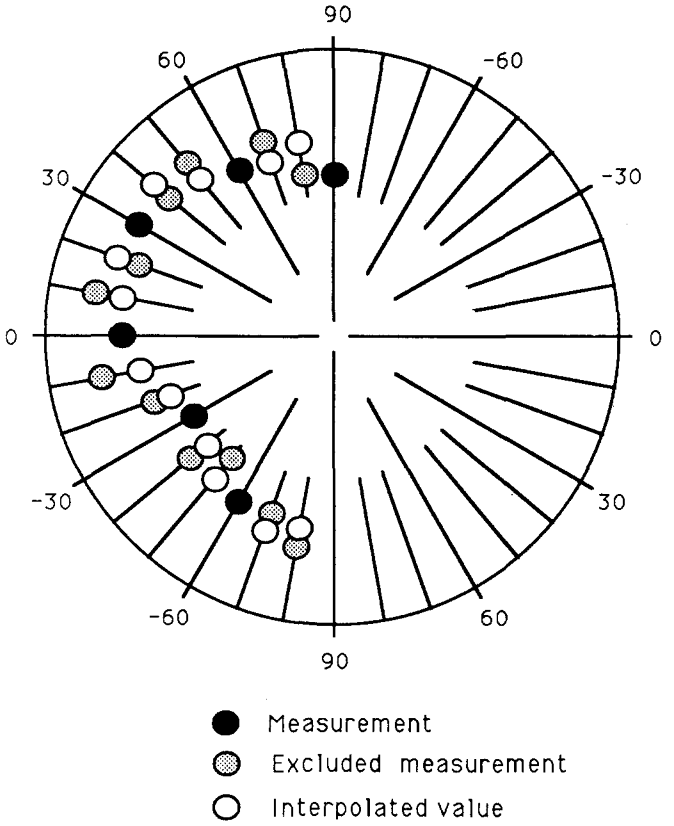

Fig. 1. A representative diagram showing how we used the Fourier interpolative algorithm to determine the mean reconstruction error as we decreased the number of views. In this example, 18 views have been measured at 10-deg intervals. Views every 30 deg *(solid circles)* are used by the algorithm to estimate by Fourier interpolation the remainder of the 10-deg images *(hollow circles)*. Since all views were in fact measured, the estimated images can be compared with the measured but excluded images *(hatched circles)*. The radial differences (as a distance) between the excluded and interpolation views provide a measure of the accuracy of the interpolation algorithm. The appendix describes the mathematical procedure in detail

checked to make sure that the whole lens image was captured with enough pupillary dilation and without obstruction by the shadow of the nose. The 35-mm photographs were digitized and processed in a standardized fashion, using a Perkin Elmer 1010MG microdensitometer as previously described [3]. The data obtained from each eye were transferred to a VAX 8350 computer system, and special software scaled all the images to the same standard using the gray step wedge. Linear microdensitometry was performed through the center of the lens through a 440 × 40-μm window, resulting in a one-dimensional profile. This profile was then used to calculate the minimum number of views required. With data from the full 18 views as reference, we determined the mean square reconstruction error using a Fourier interpolative algorithm as we decreased the number of views from 18 (every 10 deg) to nine (every 20 deg), six (every 30 deg), two (every 90 deg) and one (Fig. 1). The Fourier interpolative algorithm, a standard rigorous mathematical and statistical method, is discussed further in the appendix. The overall mean square reconstruction error for the normal lenses using one view to characterize any of the 18 views was determined and used as the threshold for acceptance (Fig. 1). If one assumes that only one view is sufficient to characterize a normal lens, then the average error using one normal view to characterize the other 17 views could be used as a threshold in comparing similar results for cataractous patients. That is, if sampling permits an error rate less than or equal to that of comparable normals for a specific type of cataract, then that sampling rate is probably sufficient. The mathematical formula and details of the algorithm are described in the Appendix.

Table 1. Mean square errors and minimum number of views for normal volunteers

No.	20°	30°	60°	90°	180°	Minimum number of views[a]
V-1	11.04	15.39	20.59	24.56	32.93	1
V-2	14.02	3.51	33.20	26.69	40.27	2
V-3	13.10	16.79	21.30	25.58	36.98	2
V-4	10.21	15.06	17.15	16.1	36.01	2
V-5	10.59	14.82	19.04	17.94	17.50	1
V-6	13.31	17.42	21.84	21.29	24.40	1
V-7	7.51	10.82	17.73	21.66	23.50	1
V-8	8.37	10.92	20.75	23.39	30.36	1
V-9	12.43	18.60	24.45	16.43	18.93	1
V-10	19.27	24.70	29.56	34.02	53.00	3
V-11	13.54	15.96	23.46	23.53	26.68	1
V-12	13.65	15.02	17.05	17.32	21.92	1
V-13	16.34	20.50	22.85	22.30	33.14	2
V-14	6.95	12.28	14.95	18.20	21.91	1
V-15	9.23	13.41	16.62	15.29	18.05	1
V-16	15.41	23.37	30.61	29.76	51.80	2
V-17	11.92	18.30	26.11	26.26	44.89	2
V-18	18.17	22.72	32.55	33.04	68.18	2
V-19	18.69	22.99	36.11	28.61	46.33	2
V-20	11.87	13.70	21.32	21.43	25.44	1
Overall	12.78	17.31	23.36	23.32	33.11	1

[a] The minimum number of views to characterize an eye is based on a mean square error threshold of 33.11 (the overall normal average error with only one view)

Table 2. Mean square errors and minimum number of views for cortical cataracts

No.	20°	30°	60°	90°	100°	Minimum number of views
C-1	15.87	19.19	40.79	44.69	52.13	6
C-2	12.69	15.89	20.19	21.44	48.44	2
C-3	18.29	27.03	37.66	42.99	53.54	6
C-4	9.39	11.78	19.17	19.67	38.34	2
C-5	11.88	15.46	24.82	23.23	34.58	2
C-6	11.69	19.50	26.00	24.53	34.38	2
C-7	18.94	25.79	41.26	50.20	73.41	6
C-8	11.43	16.48	22.74	26.02	29.14	1
Overall	13.77	18.89	29.09	31.60	45.56	2

Results

Table 1 shows mean square reconstruction errors obtained from normal lenses as we reduced the number of views from 18 to one, using the Fourier interpolative algorithm. We found that the overall mean reconstruction error for one view was 33.11 (SD = 13.42). This mean square reconstruction error value was used as a threshold in comparing similar results for cataractous patients. Figures 2 and 3 represents a 10-deg set for a normal lens and a posterior subcapsular cataract respec-

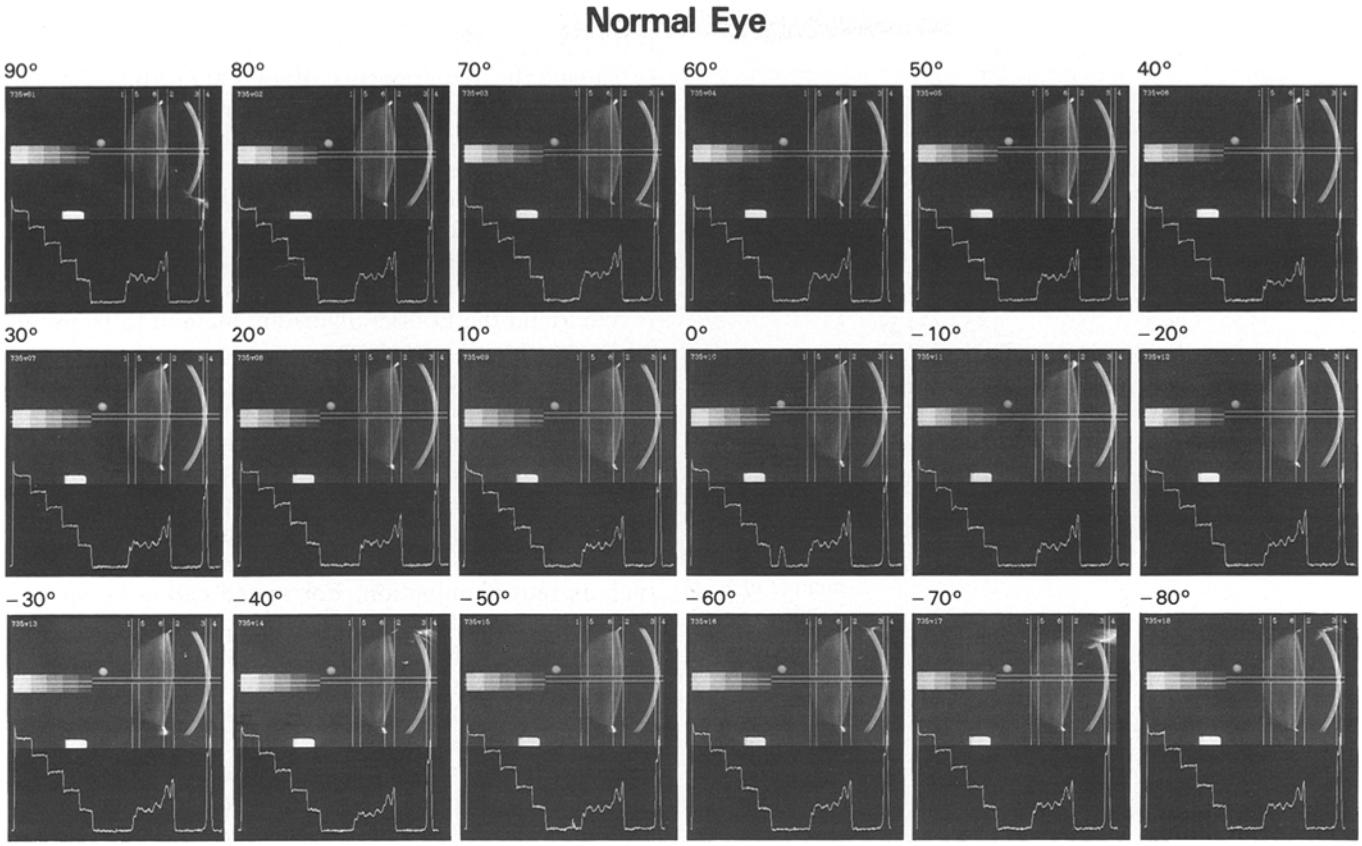

Fig. 2. Representative Scheimpflug photographs of a normal eye, taken every 10 deg rotating through the visual axis

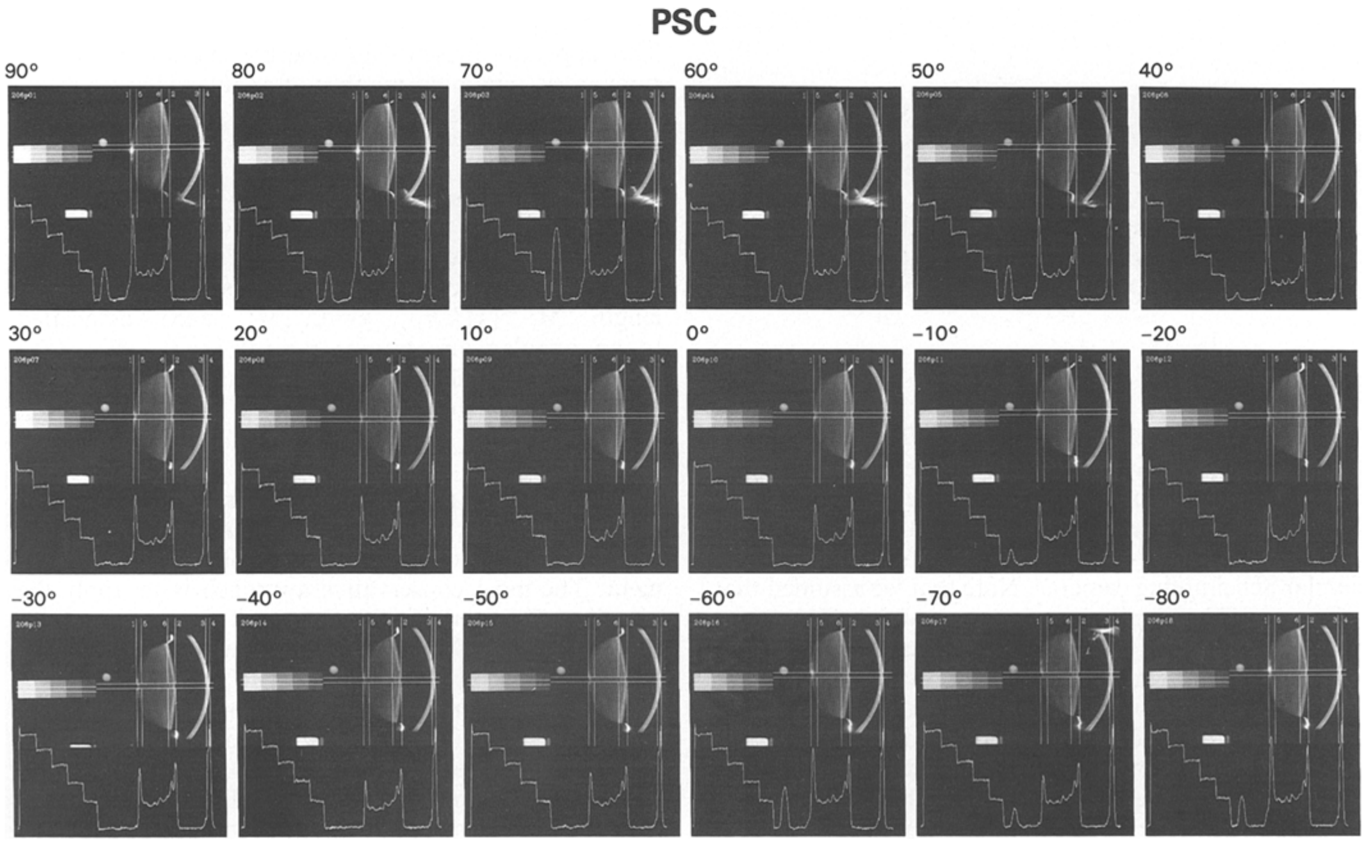

Fig. 3. Representative Scheimpflug photographs of an eye with a posterior subcapsular cataract, taken every 10 deg rotating through the visual axis. Due to the eccentric location of the opacity, it appears in different parts of the posterior capsule at different angles

Table 3. Mean square errors and minimum number of views for nuclear cataracts

No.	20°	30°	60°	90°	180°	Minimum number of views
N-1	16.80	22.63	30.52	46.60	68.05	3
N-2	13.22	24.12	29.30	26.87	33.73	2
N-3	13.15	16.44	22.61	20.70	27.96	1
N-4	16.16	21.37	33.41	31.03	45.15	6
N-5	14.08	17.54	23.42	21.00	29.66	1
N-6	17.72	26.22	35.87	30.95	34.59	6
N-7	10.36	16.67	21.79	20.14	27.78	1
Overall	14.50	20.71	28.13	28.19	38.13	2

Table 4. Mean square error and minimum number of views for psc cataracts

No.	20°	30°	60°	90°	180°	Minimum number of views
P-1	14.96	22.21	23.77	30.91	28.88	1
P-2	24.47	29.22	35.43	35.49	63.43	2
P-3	20.14	28.29	41.79	35.39	47.67	6
P-4	16.62	25.80	36.22	30.51	43.96	2
P-5	30.45	33.90	56.25	48.89	59.43	9
P-6	16.89	18.45	22.82	25.60	33.10	1
P-7	11.20	19.24	26.83	29.04	39.20	2
P-8	25.01	39.22	47.86	61.59	76.59	9
P-9	59.06	84.91	101.60	85.56	89.18	18
P-10	14.58	17.17	28.30	26.32	54.42	2
Overall	23.34	31.84	42.09	40.93	53.59	6

tively. Tables 2–4 show the mean square reconstruction errors for each pure type of cataract. We found that cortical cataracts require at least two views, nuclear cataracts at least two views, and posterior subcapsular cataracts at least six views to characterize the lenses. In each type of cataract, the minimum number of views required differed from eye to eye.

Discussion

This study uses a mathematical basis for answering the question how many views are required to adequately represent cataractous lenses with the Topcon SL-45 Scheimpflug camera. This is important for an objective description of cataracts using this system as well as other similar Scheimpflug cameras. Note that we assumed that in a normal lens only one view is required. Hence, the minimum error we used as cutoff for cataractous lenses was based on the mean square reconstruction error for one view for the normal lenses. Our study suggests that the present common practice of using one view for Scheimpflug photographs (usually the 90° view), although good for clear lenses, may not be enough as one follows these lenses over time and opacities develop. Many authors agree that the Scheimpflug system is very useful for nuclear cataractous changes, and for this, two views may be required. However, for posterior subcapsular cataracts, we found that six views may be needed to satisfy the requirements of our algorithm. This is because of the asymmetry of the density. This and the cortical type of cataract may be best studied using the Kawara retroillumination method [1, 2, 4, 8]. The finding that two views are required for cortical cataracts has to be accepted conditionally, because this method does not detect opacities which may not reach the central axis and thus do not get anlayzed by the densitometry.

We found the Fourier algorithm method to be useful in determining the minimum number of views required for the present standard of analyzing Scheimpflug photography (i.e., central linear microdensitometry). We believe this method of determining minimum views can also be used in the future when new methods of analyzing Scheimpflug pictures are developed, such as three-dimensional image analysis, which would incorporate peripheral changes, and for other lens photographic methods such as retroillumination. For mixed cataracts, special software still needs to be developed to correct the values of the parts of the lens covered by shadows cast by opacities in the more anterior regions. Until this software developed, we believe studies using the Scheimpflug camera will need to be confined to pure cataract types, normal changes, and those mixed cataracts where the cortical opacities are confined to the periphery (no shadows cast centrally).

Appendix

This appendix presents an objective method for determining the minimum number of angular measurements for cataract assessment.

Statement of the problem

The data that are extracted for cataract classification consist of a set of $N=18$ one-dimensional signals of length M: $\{x(k,\theta_i),\ k=1,\ldots M\}$, each associated to an angular orientation: $\theta_i=i\Delta\theta$, $i=0,\ldots N-1$ with $\Delta\theta=\pi/N$ (e.g., $\Delta\theta=10°$). By construction, the data have an angular period of 180°:

$$x(k,\theta_i),=x(k,\theta_i+\pi) \tag{1}$$

The problem is to determine the minimum sampling step, $\Delta\theta^*$, such that we have an overall characterization of the patient that is sufficient for complete cataract assessment. The most conservative approach is to apply the sampling theorem, which states that the angular sampling frequency should be at least twice the maximum angular frequency of the data [9]. In this circumstance, the data may be reconstructed without any loss in any angular orientation using interpolation. When the sampling is below the Nyquist frequency, the interpolation will result in a reconstruction error. In our case, we are ready to tolerate a certain reconstruction error provided that it remains sufficiently low, that is, within the range of variability of the data.

Angular reconstruction using the FFT

We will now consider that our data has been measured at the finest possible angular resolution $\Delta\theta$. Reduced data sets $\{x_K(k,\theta'_i),\ k=1,\ldots M\}$, where $\theta_i = i\Delta\theta', i=,0\ldots,N/K$ and $\Delta\theta' = K\Delta\theta$, are obtained by subsampling the initial data by any factor K that divides N (e.g., $K=2$, 3, 6, 9, and 18). This procedure generates measurements corresponding to coarser angular sampling steps. Based on such a sequence, the data at finer resolution may be reconstructed by interpolation. Since the data are periodic in the angular direction, it is particularly suitable to use a procedure based on the fast Fourier transform algortihm which allows perfect reconstruction provided that the sampling theorem is satisfied. For a given k, we compute an $N'=N/K$-point Fourier transform $\{X(k,n'),\ n=0,\ldots,N'-1\}$ and generate an N-point transform $\{X_K(k,n), n=0,\ldots,N-1\}$ using the following rule:

$$\begin{aligned}
&X_K(k,n) = X(k,n), && n=0,\ldots,[(N'-1)/2] \\
&X_K(k,N-n) = X(k,N'-n), && n=1,\ldots,[(N'-1)/2] \qquad (2) \\
&X_K(k,n) = 0, && \text{otherwise}
\end{aligned}$$

This defines and equivalent band-limited signal with a periodicity of N. Note that when N' is odd, we must also reallocate the central Fourier coefficient $(n'=N'/2)$ by using the relationship: $X_K(k,N'/2) = X_K^*(k,N-N'/2) = X(k,N'/2)/2$. The reconstructed signal $\hat{x}_K(k,\theta' i)$ is then simply obtained by taking an N-point inverse Fourier transform. Following this procedure, a global average reconstruction error is measured by

$$\varepsilon_K = \frac{1}{MN} \sum_{k=1}^{M} \sum_{i=0}^{N-1} [x(k,\theta_i) - \hat{x}_K(k,\theta_i)]^2 \qquad (3)$$

The reconstruction algorithm guarantees that $x(k,\theta_i) - \hat{x}_K(k,\theta_i) = 0$, for $i=0, K, 2K,\ldots,KN'$, so that the error is entirely due to the missing samples.

Criterion for minimum number of views

The error defined by Eq. 3 is computed for every patient as a function of K. We may also evaluate average reconstruction errors for a particular group of patients. Since ε_K is mostly an increasing function of K, the minimum number of views (N/K) is determined by requiring the approximation error to be below an acceptable baseline σ_0^2. For our purpose, we have chosen σ_0^2. to be the within-group variance estimated on a group of normal subjects.

References

1. Brown N, Bron A, Ayliffe W, Sparrow J, Hill A (1987) The objective assessment of cataract. Eye 1:234–246
2. Chen S, Chylack L, White O (1985) Topcon SL-45 photography, a suitable technique for documenting nuclear but not cortical cataractous change in vivo. Invest Ophthalmol Vis Sci 25A:119
3. Datiles M, Edwards P, Trus BL, Green S (1987) In vivo studies on cataract using the Scheimpflug slit lamp camera. Invest Ophthalmol Vis Sci 28:1707–1710
4. Datiles M, Podgor M, Sperduto R, Kashima K, Edwards P, Hiller R (1989) Measurement error in assessing the size of posterior subcapsular cataracts from retroillumination photographs. Invest Ophthalmol Vis Sci 30:1848–1854
5. Dragomirescu V, Hockwin O, Koch H (1978) Development of new equipment for rotating slit image photography according to Scheimpflug's principle. Interdiscip Top Gerontol 13:118–130
6. Edwards P, Datiles M, Unser M, Trus B, Fridolin V, Kashima K (1990) Automated cataract classification of cataract using Scheimpflug camera. Curr Eye Res 9:517–524
7. Hockwin O, Dragomirescu V, Laser H (1969) Mesurement of lens transparency or disturbances by densitometric image analysis of Scheimpflug photographs. Graefes Arch Clin Exp Ophthalmol 219:255–262
8. Kawara T, Obazawa H (1980) A new method for retroillumination photography of cataractous lens opacities. Am J Ophthalmol 90:186–189
9. Middleton D (1980) An introduction to statistical communication theory. McGraw Hill, New York, pp 206–210