CLINICAL STUDY

The phacoemulsification learning curve: per-operative complications in the first 3000 cases of an experienced surgeon

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Abstract

Purpose **To assess the per-operative complications occurring during the first 3000 phacoemulsification cases performed by an experienced consultant surgeon.**
Methods **A prospective analysis of 3000 consecutive cases performed without supervision between November 1992 and November 1998 was carried out. Data recorded for each case included details of per-operative complications, pre-operative best corrected visual acuity, nuclear density, history of previous pars plana vitrectomy, and whether phacoemulsification was performed as part of a phacotrabeculectomy procedure.**
Results **The overall rate of vitreous loss was 1.3%. Nuclear fragments were lost to the vitreous in 6 cases (0.2%). The initial rate of vitreous loss was 4.0% in the first 300 cases falling to 0.7% in the last 300 cases. Capsulorhexis failure was the commonest per-operative complication observed, but the risk of subsequent posterior capsule rupture fell significantly from 9 of 45 (20.0%) in the first 100 cases to 1 of 49 (2.0%) in the next 2000 cases ($p = 0.0061$, Fisher's exact test). There was a significant increase in risk with denser cataracts, especially for capsulorhexis failure, rising to over 35% in the densest cases. The increases in posterior capsule rupture and vitreous loss were less dramatic but nonetheless very significant. There was no significant increase in the risk of per-operative complications with phacotrabeculectomy, and no increased risk in patients who had previously undergone pars plana vitrectomy. Posterior capsule rupture occurred in 22 of 612 (3.6%) local anaesthesia cases compared with 31 of 2269 (1.4%) topical anaesthesia cases. Per-operative best corrected visual acuity of 6/9 or better was recorded in 2.0% of the first 1000 cases compared with 13.9% of the last 1000 cases.**
Conclusions **(1) Per-operative surgical risks could be reduced to low levels during the learning curve, but complications continued to occur at a low frequency. (2) The risk of per-operative complications was not significantly elevated in previously vitrectomised eyes. (3) Nuclear density correlated significantly with per-operative complication risk. (4) The visual threshold for cataract surgery fell dramatically with increasing experience of phacoemulsification. (5) Topical anaesthesia was not associated with an increased risk of per-operative complications.**

Key words Complications, Learning curve, Phacoemulsification, Risk, Vitreous loss

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During the last few years, phacoemulsification has become the preferred method of cataract surgery in the USA[1] and has become increasingly popular in the UK. There have been a number of published studies examining the incidence of complications during the 'learning curve' for phacoemulsification[2–13] but most have considered the experience of surgeons in training[2–7] and have reported the results for individual surgeons over a relatively small number of cases. Tabandeh *et al.*[6] prospectively analysed the complications of the first 160 phacoemulsification procedures performed by three surgeons in training and found the incidence of posterior capsular tear to be 4.4% and vitreous loss to be 3.8%. Literature review reveals the rate of posterior capsule rupture in the first 100 patients to be 5–15%[4,6,7] and the rate of vitreous loss to be 1–8%.[6,9,10] There are few studies, however, examining how the frequency of per-operative complications varies after the initial few hundred cases. We prospectively analysed the per-operative complications over the first 3000 phacoemulsification procedures performed by a single, experienced consultant vitreo-retinal

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surgeon (R.L.B.). To our knowledge, this is by far the largest series yet published and it demonstrates how the risk of significant complications during phacoemulsification reduces once the initial phase of the learning curve is over.

Materials and methods

Data collection

Details of each of the first 3000 cases, performed between November 1992 and November 1998, were recorded prospectively at the time of operation. Information recorded included the pre-operative best corrected visual acuity, estimated nuclear density (Table 1), site of incision (usually superior or temporal scleral tunnel), anaesthetic used (topical, peribulbar, sub-Tenon's or general anaesthesia), whether the patient had previously undergone pars plana vitrectomy, and whether the patient underwent phacoemulsification alone, phacotrabeculectomy or phacoemulsification as a prelude to pars plana vitrectomy. For each case, it was noted whether or not any of the following occurred: capsulorhexis failure, posterior capsule rupture, vitreous loss, dropped nuclear fragment, iris trauma, zonule rupture, or 'other complication'. The stage of the operation at which any complication occurred was also recorded.

Patient selection

After the first 200 cases, phacoemulsification was attempted in all patients undergoing cataract surgery during the period of the study. The first 3000 cases were included in the analysis. This included 2643 phacoemulsifications alone, 317 phacotrabeculectomies and 40 cases where phacoemulsification was performed immediately prior to pars plana vitrectomy.

Anaesthesia

Three different anaesthetic techniques were used during the study. Local anaesthesia (LA) involved either peribulbar or sub-Tenon's injection of 2% lignocaine prior to cataract surgery. Topical anaesthesia (TA) involved pre-operative application of 1% amethocaine only. General anaesthesia (GA) was used for the remaining cases.

Table 1. *Classification of nuclear density*

Phaco power on first groove	Nuclear density
0–29%	1+
30–49%	2+
50–79%	3+
80–100%	4+
100% with difficulty	5+

Surgical technique

Following construction of a superior or temporal scleral tunnel, the anterior chamber was filled with a viscoelastic (Healonid, Pharmacia and Upjohn). A 1 mm corneal paracentesis was then formed. Continuous curvilinear capsulorhexis was performed with forceps. A Corydon or Pearce cannula (Visitec) was used for hydrodissection with Balanced Salt Solution. Phacoemulsification was performed using the Surgical Design (cases 1 to 753) or Storz Premiere (cases 754 to 3000), both of which use an identical tip design. A deep primary groove was formed initially and the maximum phacoemulsification power required at this stage was recorded as an estimate of nuclear density (Table 1). The nucleus was fragmented using either the 'divide and conquer' technique as described by Gimbel[14,15] or a modified Koch 'stop and chop' technique.[16] Automated irrigation/aspiration of remaining soft lens material was followed by intraocular lens implantation: 5 mm PMMA lenses (Pharmacia and Upjohn) for the first 2494 cases, 5 mm Acrysof acrylic foldable lenses (Alcon) for the last 506 cases. The viscoelastic was carefully removed at the end of the procedure.

Results

The overall complication rates for the 3000 cases are shown in Table 2. The most common complication, at 3.1% of all cases, was capsulorhexis failure. Vitreous loss occurred in 1.3%. The most serious complication, per-operative suprachoroidal haemorrhage, occurred in 2 cases (0.07%), although for both these patients the final visual outcome was good. The first patient (case 810) achieved a final corrected visual acuity of 6/9 following delayed vitrectomy, removal of lens fragments and secondary lens implantation. The second patient (case 2778) achieved a final corrected acuity of 6/6 following resolution of the haemorrhage and secondary lens implantation.

Learning curve

Fig. 1 and Table 3 show how the incidence of capsulorhexis failure, posterior capsule rupture and vitreous loss varied with experience. The initial rate of vitreous loss in the first 300 cases was 4.0%, falling to 0.7% in the last 300 cases of the series. Capsulorhexis failure was the commonest per-operative complication observed, although the risk of subsequent posterior

Table 2. *Overall complications in the 3000 cases*

	No. of cases	% of total cases
Capsulorhexis failure	94	3.1%
Posterior capsule rupture	52	1.7%
Vitreous loss	40	1.3%
Nucleus dropped	6	0.2%
Iris trauma	11	0.4%
Zonule rupture	10	0.3%
Suprachoroidal haemorrhage	2	0.07%

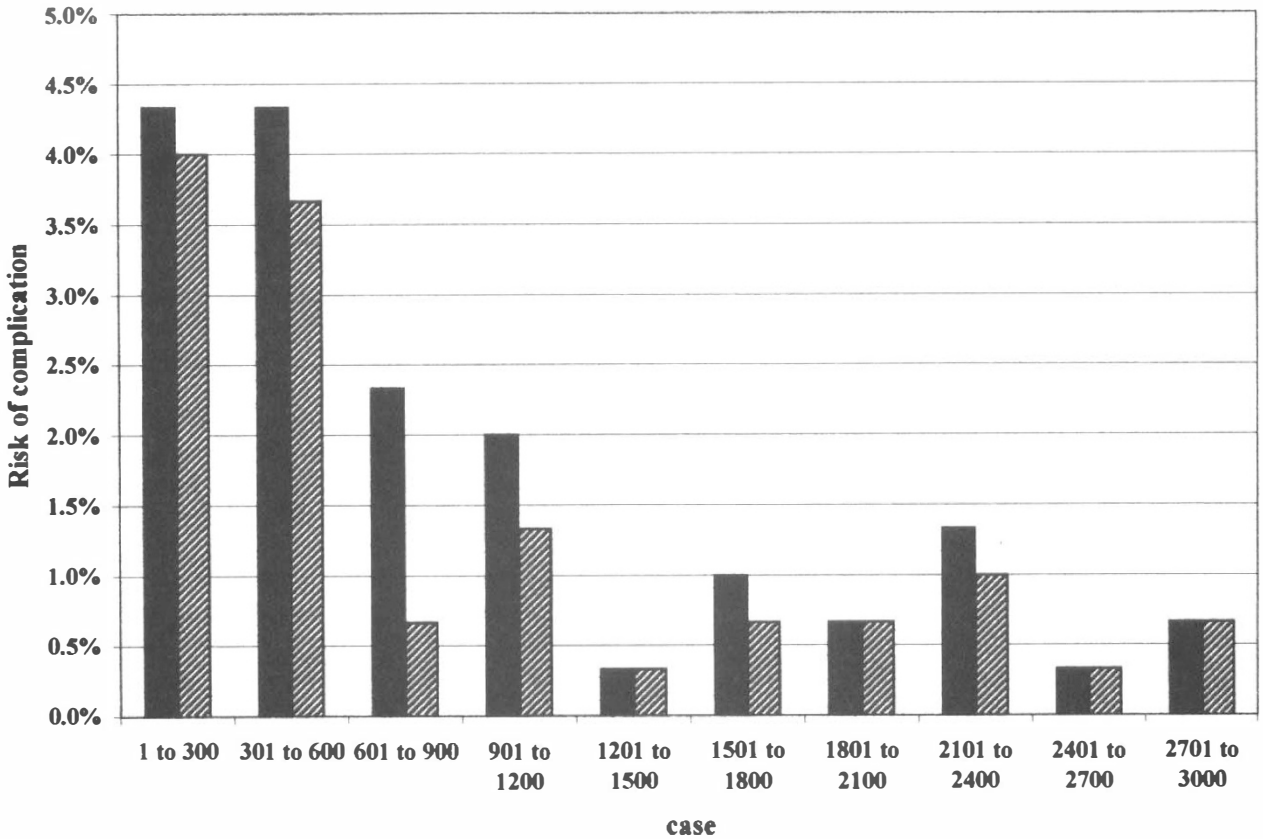

Fig. 1. *The risk of posterior capsule rupture (black columns) and vitreous loss (diagonally hatched columns) in each consecutive group of 3000 cases.*

capsular rupture and vitreous loss fell significantly with experience. In the first 1000 cases there were 45 capsulorhexis failures of which 9 went on to posterior capsular tear (20.0%), whereas in the next 2000 cases, with 49 capsulorhexis failures, there was only 1 posterior capsular tear (2.0%) ($p = 0.0061$, Fisher's exact test).

Stage of complication

The risk of posterior capsular rupture during the phacoemulsification stage of the operation fell significantly with experience. There were 27 posterior capsule ruptures in the first 1000 cases (2.7%) during phacoemulsification compared with only 2 (0.2%) in the last 1000 cases ($p < 0.0001$, Fisher's exact test). The rate of posterior capsule rupture during the aspiration of soft lens matter remained relatively constant (Table 4).

Effect of nuclear density

The risk of complications increased dramatically with estimated nuclear density (Fig. 2). Capsulorhexis failure occurred in only 21 of 1278 cases (1.6%) with '1+' nuclear sclerosis compared with 32 of 140 cases (22.9%) with '4+'

Table 3. *Pre-operative visual acuity, anaesthesia technique used and per-operative complications in each consecutive group of 300 patients*

Case nos.	Pre-operative VA ≥ 6/9	Anaesthesia technique used			Per-operative complications		
		TA	LA	GA	CCC failure	PC rupture	Vitreous loss
1 to 300	3 (1.0%)	29 (9.7%)	254 (84.7%)	17 (5.7%)	16 (5.3%)	13 (4.3%)	12 (4.0%)
301 to 600	5 (1.7%)	142 (47.3%)	148 (49.3%)	10 (3.3%)	7 (2.3%)	13 (4.3%)	11 (3.7%)
601 to 900	9 (3.0%)	136 (45.3%)	154 (51.3%)	10 (3.3%)	17 (5.7%)	7 (2.3%)	2 (0.7%)
901 to 1200	12 (4.0%)	266 (88.7%)	28 (9.3%)	6 (2.0%)	17 (5.7%)	6 (2.0%)	4 (1.3%)
1201 to 1500	14 (4.7%)	282 (94.0%)	8 (2.7%)	10 (3.3%)	8 (2.7%)	1 (0.3%)	1 (0.3%)
1501 to 1800	31 (10.3%)	283 (94.3%)	5 (1.7%)	12 (4.0%)	5 (1.7%)	3 (1.0%)	2 (0.7%)
1801 to 2100	21 (7.0%)	288 (96.0%)	7 (2.3%)	5 (1.7%)	6 (2.0%)	2 (0.7%)	2 (0.7%)
2101 to 2400	36 (12.0%)	276 (92.0%)	2 (0.7%)	22 (7.3%)	10 (3.3%)	4 (1.3%)	3 (1.0%)
2401 to 2700	50 (16.7%)	284 (94.7%)	4 (1.3%)	12 (4.0%)	4 (1.3%)	1 (0.3%)	1 (0.3%)
2701 to 3000	46 (15.3%)	283 (94.3%)	2 (0.7%)	15 (5.0%)	4 (1.3%)	2 (0.7%)	2 (0.7%)
Total	227	2269	612	119	94	52	40

VA ≥ 6/9, initial visual acuity 6/9 or better; CCC failure, continuous curvilinear capsulorhexis failure; PC, posterior capsule; TA, topical anaesthesia only; LA, sub-Tenon's or peribulbar anaesthesia; GA, general anaesthesia.

Table 4. *Stage of operation at which posterior capsule rupture occurred*

Case nos.	Stage of complication				
	Phaco	IA	Hydrodissection	IOL insertion	Enlarging paracentesis
1 to 1000	27	3	2	2	0
1001 to 2000	7	4	0	0	0
2001 to 3000	2	4	0	0	1

Phaco, phacoemulsification; IA, irrigation/aspiration of soft lens matter; IOL, intraocular lens.

nuclear sclerosis ($p < 0.0001$, Fisher's exact test). The risks of posterior capsule rupture and vitreous loss were also markedly increased (Fig. 2).

Effect of other procedures

The risk of capsulorhexis failure associated with phacotrabeculectomy was significantly lower than with phacoemulsification alone ($p = 0.026$, chi-square with Yates' correction = 4.953). There was no significant difference in the risk of posterior capsule rupture and vitreous loss between cases undergoing phacoemulsification alone and those undergoing phacotrabeculectomy (Table 5). Posterior capsule rupture or vitreous loss did not occur in any of 59 eyes which had previously undergone pars plana vitrectomy.

Effect of anaesthetic used

Overall, posterior capsule rupture occurred in 22 of 612 (3.6%) LA cases (peribulbar or sub-Tenon's local anaesthetic) compared with 31 of 2269 (1.4%) TA cases. Although this difference is significant ($p = 0.0005$, chi-square with Yates' correction = 12.051), it should be noted that few TA cases were carried out during the early part of the series when the surgeon was less experienced (Table 3); when only the first 1000 cases were considered, there was no significant difference between the complication rates with TA and LA.

Initial best corrected acuity

In the first 1000 cases, 20 (2%) had an initial visual acuity of 6/9 or better compared with 139 (13.9%) in the last 1000 cases (Fig. 3).

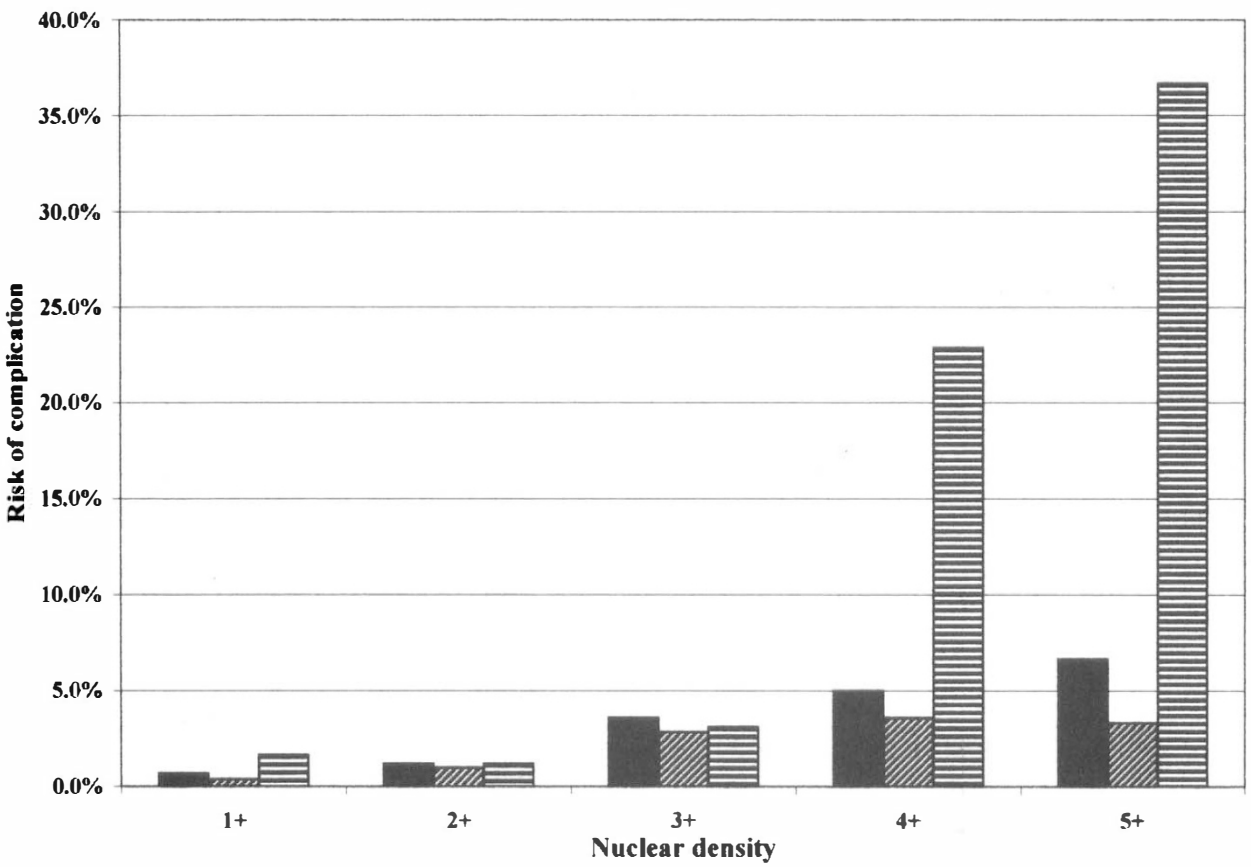

Fig. 2. *The effect of nuclear density on the risk of capsulorhexis failure (horizontally hatched columns), posterior capsule rupture (black columns) and vitreous loss (diagonallly hatched columns).*

Table 5. *Complications by additional procedure*

	Total	CCC failure	PC rupture	Vitreous loss
Phaco only	2584 (86.1%)	89 (3.4%)	49 (1.9%)	37 (1.4%)
Phacotrabeculectomy	317 (10.6%)	3 (0.9%)	2 (0.6%)	2 (0.6%)
Phacovitrectomy[a]	40 (1.3%)	0	1 (2.5%)	1 (2.5%)
Past vitrectomy[b]	59 (2.0%)	2 (3.4%)	0	0

CCC failure, continuous curvilinear capsulorhexis failure; PC, posterior capsule.
[a]Phacoemulsification procedure performed immediately prior to pars plana vitrectomy.
[b]Patients had previously undergone pars plana vitrectomy.

Discussion

To our knowledge, this study is the largest reported single-surgeon series of phacoemulsification procedures analysed prospectively from the first case performed. One feature of our series was the relative lack of patient selection for phacoemulsification. After the first 200 cases, the procedure was attempted on all patients with cataract undergoing surgery. In only 3 cases out of 3000 was the decision made to convert to extracapsular cataract extraction; in all 3 cases, the reason for conversion was excessive lens hardness. Despite this lack of selection, the overall complication rates compare favourably with other published series. The overall vitreous loss rate in our series was 1.6% compared with 2.2% in 2204 cases by 13 experienced surgeons in Liverpool reported by Ah-Fat *et al.*[11] and 1.5% in a highly selected 400 case, single-surgeon series reported by Seward *et al.*[9]

One factor contributing to the complication rates early in our series may well have been the lack of experienced supervision. The surgeon had some previous experience of capsulorhexis, having performed approximately 200 cataract operations using capsulorhexis and viscoexpression prior to the start of the study, but experienced guidance in other aspects of phacoemulsification surgical technique may have reduced the initial complication rates.

One striking change during the course of the study was the lowering of the threshold for cataract surgery with the introduction of phacoemulsification (Fig. 3). Only 1% of the first 300 cases had a pre-operative best corrected visual acuity of 6/9 or better compared with 15.3% in the last 300 cases. Obviously this trend towards earlier surgery may have been an additional factor affecting the risk of complications in addition to the learning curve of the surgeon.

It was interesting to find that per-operative complication rate for phacotrabeculectomy was not significantly greater than for phacoemulsification alone. Indeed, the risk of capsulorhexis failure was significantly lower. This may be because the combined procedure tended to be performed in relatively 'easier' eyes. It should, however, be noted that post-operative complications and visual outcome were not considered in the present study.

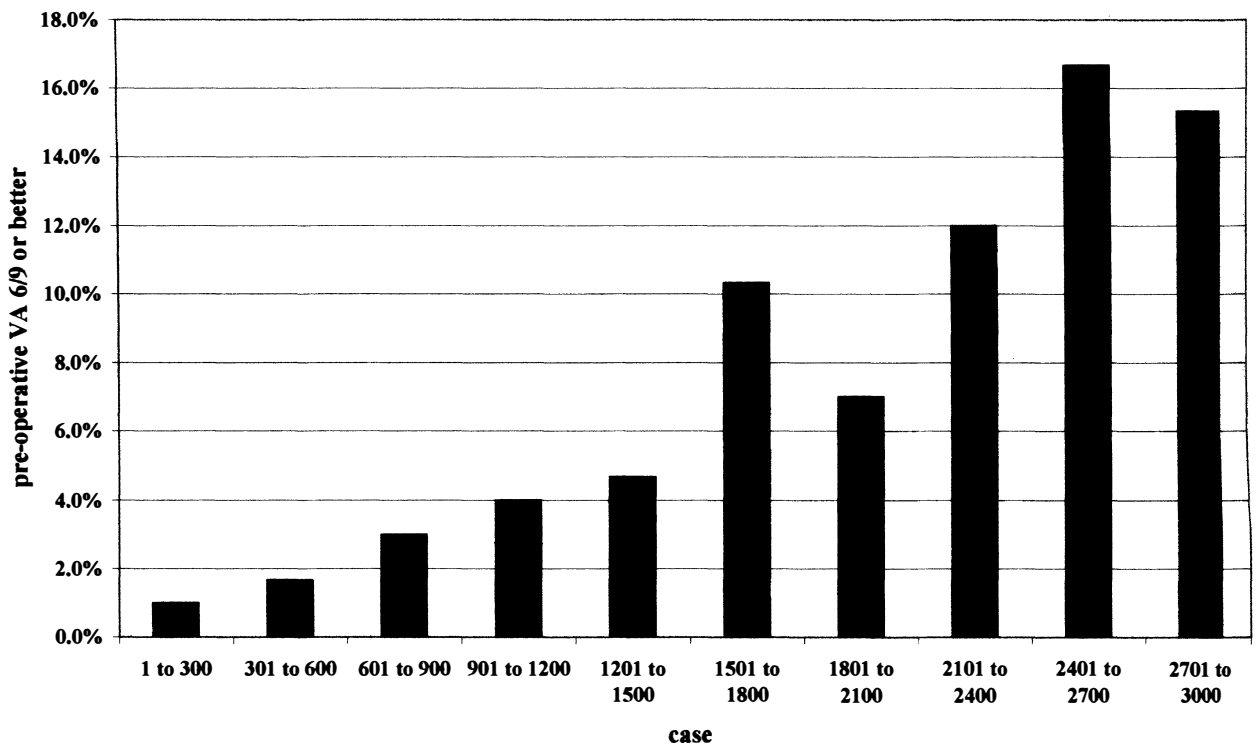

Fig. 3. *Percentage of cases with a pre-operative visual acuity of 6/9 in each consecutive group of 300 cases.*

In contrast to the study by Lacalle *et al.*,[8] we did not find an increased risk of complications in previously vitrectomised eyes – there were no episodes of posterior capsule rupture in 59 eyes which had had previous pars plana vitrectomy. This may, in part, be due to the vitreoretinal interest of the surgeon, but it does suggest that phacoemulsification can be performed safely in vitrectomised eyes.

Estimated nuclear density was significantly correlated with the risk of per-operative complications (Fig. 2). Posterior capsule rupture occurred in 9 of 1278 cases with '1+' nuclear sclerosis (0.7%) compared with 7 of 140 cases (5%) with '4+', and 5 of 30 cases (16.7%) with '5+'. The increased risk of capsulorhexis failure with increasing nuclear density was even more dramatic, reaching 36.7% in '5+' cases. It therefore seems likely that earlier surgery can reduce the risk of per-operative complications with phacoemulsification, although recent evidence suggests that the use of agents such as indocyanine green[17] or trypan blue[18] to stain the anterior capsule in difficult cases can markedly improve capsulorhexis success rates. For the purposes of this study we used the maximum phacoemulsification power required to complete the first groove as an estimate of nuclear density. It should be pointed out that this is not an established classification system, but it allowed us to obtain an estimate of the lens 'hardness', which is the lens property of principal concern in phacoemulsification surgery. Previous studies[19,20] have established a correlation between lens hardness (assessed by automated lens guillotine following extracapsular cataract surgery) and the degree of visible nuclear sclerosis (assessed by nuclear colour and opalescence according to the Lens Opacities Classification System II[21]). The relationship has been found to hold for non-mature[19] and mature[20] cataracts, but it was not possible in either study to predict lens hardness on the basis of nuclear colour and opalescence alone: the predictions were more accurate if other factors such as the age of the patient were considered. Our classification was adopted as a simple, direct and repeatable estimate of nuclear density, but further work would be required to correlate it with other more established classification systems.

Our series also demonstrates that there is no significant increase in the risk of pre-operative complications when topical anaesthesia is used as the anaesthetic method of choice, although it should be noted that topical anaesthesia was not used frequently on the early part of the 'learning curve'.

Overall, our study shows that although pre-operative complication rates with phacoemulsification can be reduced markedly with increasing experience of the surgeon, complications continue to occur at a low rate. Phacoemulsification, even in the hands of an experienced surgeon, still carries risks.

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