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CLINICAL STUDY

A different approach to assess resident phacoemulsification learning curve: analysis of both completion and complication rates

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Abstract

Purpose **To assess phacoemulsification learning curve by analysing residents' surgical completion and complication rates.**
Methods **This prospective study included 226 cases of phacoemulsification performed by 11 senior residents under a single supervisor during a 27-month period. Both completion and complication rates were collected to assess their surgical results. 'Short-term completion rate (STCR)', the frequency of the surgeries completed exclusively by the residents during every five consecutive cases, was used in the evaluation of the learning curve parameter.**
Results **These residents could complete phacoemulsification independently in 101 surgeries (44.7%). Intraoperative complications occurred in 62 cases (27.4%), of which 11 cases were complicated with vitreous loss (4.9%). By tracing different residents' individual STCRs, we found that the learning curve for phacoemulsification surgery to be of an exponential pattern, and the first STCR of 60% to be a good representation of the exponential point. Before the residents' first STCR of 60%, their average completion rate was only 16.7% and complication rate was as high as 39.2%. While after that point, the average completion rate accelerated to 76.4% and complication rate decreased to 14.2%.**
Conclusion **The learning curve of phacoemulsification is of an exponential pattern and the trainees' STCR can be a useful parameter to evaluate their surgical performance.**
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Keywords: phacoemulsification; learning curve; completion rate; complication rate

Introduction

Surgical results, mainly the rate of intraoperative complications, of phacoemulsification performed by residents were reported to be variable. For example, the rate of vitreous loss among resident surgeons varied from 1.8 to 14.7%.[1–9] It was emphasized that surgical complications decreased with proper training and supervision.[3,4,6–8] However, the level of supervisors' participation in the surgery has not been well-documented in previous studies. Generally, the supervisors could prevent some dangerous or inappropriate movements, or take over the surgery if potentially serious complications occurred. Their active or passive attitude in the intervention of the surgery somewhat modifies the incidence of complications. Therefore, surgical results of the trainees should not be evaluated solely on the complication rate. The percentage of phacoemulsification performed exclusively by the residents, or the completion rate, should also be considered as another critical aspect in resident surgical training.

Both complication and completion rates are related to each other. The chances of experiencing a complication decrease by 1% with each successive case during training.[10] Using complication rate as a parameter, phacoemulsification learning curve is generally accepted to be quite steep.[3,5,10–14] However, in a patient-based practice, most supervisors will try

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their best to avoid a high complication rate of the trainee surgeons. Therefore, completion rate, rather than complication rate, is more appropriate in describing the learning curve of phacoemulsification under supervision. This study aimed to analyse our residents' learning process of phacoemulsification by using completion rate as a major parameter.

Materials and methods

We prospectively collected surgical results of phacoemulsification performed by 11 third or fourth year residents under one supervisor (J-S Lee) from July 2005 through September 2007 at Chang Gung Memorial Hospital (CGMH). Surgical trainings of various components of phacoemulsification procedure ('part-phaco') begin in the first 2 years of residency at CGMH. During the last 2 years, training course shifts to include performing a complete procedure ('full-phaco'). Before entering in this study, these residents had also attended several lectures and at least one wet lab on phacoemulsification.

The training period for each resident in this study was successive but not equivalent, lasting from 2 to 6 months. Simultaneously, these residents might also receive other supervisors' training on phacoemulsification. The interval between the residents' each operation in this study was almost equivalent. Therefore, surgical results of each resident in this study might represent a relatively continuous fragment of his or her learning process for phacoemulsification. Each week in this study, the supervisor would select one to three cases with lower 'cataract surgery risk scores'[15] from a list of four to eight patients for the residents to perform phacoemulsification. Overall, 226 cases were included in this study.

After providing informed consent, all patients received a uniform surgical technique under peribulbar anaesthesia. In this study, we divided phacoemulsification into five steps: step 1 (incision): clear corneal and side-port incision; step 2 (CCC): continuous curvilinear capsulorhexis; step 3 (phaco): hydrodissection, hydrodelineation, and emulsification of nucleus; step 4 (I/A): irrigation/aspiration of cortex; and step 5 (IOL): IOL insertion and wound closure.

To supervise the surgeries, the trainer might occasionally provide verbal suggestion for the trainees when the operation did not proceed smoothly. However, if any of the following occurred: three unsuccessful trials in the same procedure, a capsulorhexis extending to iris margin, repeatedly prolapsed iris, any dangerous movement, or residents' active request for help, the supervisor was obliged to discontinue or take over the surgery. After the problems were solved, the resident could always resume as a primary surgeon. However, if an extending capsulorhexis that formed a radial tear during CCC or any major complication as in a posterior capsule (PC) rupture, the remaining surgery would be taken over by the supervisor. On the contrary, if a CCC tear was found at a later step such as after nucleus emulsification, the resident was allowed to continue the surgery as a primary surgeon and asked to proceed with extreme caution to prevent further extension of the tear to the PC.

The following data were recorded immediately after the operation: whether or not the surgery was performed exclusively by the resident, and the occurrence of any intraoperative complication such as iris trauma, capsulorhexis failure, zonular dehiscence, PC rupture, vitreous loss, or dropped nuclear fragment. If a surgery was not entirely completed by the resident, the steps at which the supervisor intervened and the events that occurred intraoperatively were recorded.

The 'completion rate' was determined by the frequency of surgery completed exclusively by the residents even under verbal assistance. Once the supervisor took the position of primary surgeon, the surgery or the step was not considered as 'completion' for the resident. The 'complication rate' was the frequency of events complicated by the residents only as primary surgeons. Complications that occurred during the supervisor's performances were excluded from the residents' complication rate in this study.

'Short-term completion rate (STCR)', the frequency of the surgeries completed exclusively by the residents during every five consecutive cases, was used to analyse each resident's surgical result. In this study, we used STCRs of 40, 60, and 80% as three different landmarks to examine the timing of each resident's first achievement of these points during their learning process. Residents' average surgical result before and after such milestone were compared. Statistical method for comparison was the unpaired, two-tailed *t*-test.

Results

Of the 226 phacoemulsification surgeries, our residents could independently complete 101 cases, in which 11 minor complications occurred. Of the remaining 125 incomplete cases, our residents either encountered a major complication in 47 cases or received supervisor's assistances in 78 cases, in which five minor complications occurred (in 4 cases). Of the total 63 complications (in 62 cases), 11 cases were complicated with vitreous loss, representing an overall vitreous loss rate of 4.9% (11/226).

All the 63 complications are shown in Table 1. Since 47 surgeries with major complication were entirely taken over and managed carefully by the supervisor, there was

Table 1 Overall completion and complication rates in each step and the whole procedure of phacoemulsification performed by the residents

Surgical step	*Completion rate*	*Complication rate*	*Complications* (n)[a]
1. Incision	100% (226/226)	0.4% (1/226)	Corneal injury (1)[b]
2. Capsulorhexis	80.5% (182/226)	10.2% (23/226)	Capsulorhexis failure (21), iris prolapse (2)
3. Phaco (hydrodissection/hydrodelineation and emulsification of nucleus)	61.1% (124/203)	13.3% (27/203)	Iris prolapse (3), iris trauma (8)[b], vitreous loss (10), PC rupture (2), zonular dehiscence (1), capsulorhexis tear (3)[b]
4. I/A (irrigation/aspiration of cortex)	94.1% (176/187)	5.3% (10/187)	Vitreous loss (1), PC rupture (5), capsulorhexis tear (4)[b]
5. IOL insertion	98.3% (178/181)	1.1% (2/181)	PC rupture (2)
Whole procedure	44.7% (101/226)	27.4% (62/226)	63 events (in 62 cases)

IOL = intraocular lens; PC = posterior capsule.
[a]Complications were noted during this surgical step but may not indicate that the aetiology was of the similar source, eg, iris prolapse found in step 2 or 3 was probably related to a poor wound incision in step 1.
[b]These 16 'minor' complications were not severe enough to cause the supervisor to interfere in the surgery (on the contrary, the other 'major' complications were severe or potentially severe that the supervisor took over the rest of the surgery).

no dropped nuclear fragment in this study. In addition, the supervisor helped in performing part of the surgical procedure in 78 cases, of which 12 cases received two kinds of assistance. Of the total 90 successful assistances, 21 occurred during capsulorhexis (to pull back an extending rhexis), 63 occurred during phacoemulsification (mostly to disassemble the nucleus), 5 occurred during cortex aspiration (to aspirate cortex near corneal incision), and 1 occurred during IOL implantation (to release an IOL loops adhesion).

Overall, our residents' surgical completion rate of phacoemulsification was 44.7% and intraoperative complication rate was 27.4% (Table 1). In all five steps, both completion and complication rates were inversely related to each other, ie, a higher completion rate in association with a lower complication rate, and vice versa. Owing to its highest complication rate and lowest completion rate, nucleus emulsification (step 3) was our residents' most difficult step, followed by capsulorhexis (step 2) and I/A (step 4).

The residents' individual surgical results are shown in Table 2. Each resident's first achievement of an STCR of 40% (underlined), 60% (shaded), and 80% (crossed out) are also shown, respectively. All residents could achieve an STCR of 40%, but its occurrence was not followed by another occurrence of STCR of 60% in three surgeons. Eight residents could achieve an STCR of 60%, and its occurrence, acted like a 'tipping point', where a rapid achievement of another STCR of 80% followed. Both completion and complication rates were somewhat inversely related to each other. The timing of the first achievement of STCR of 60% was also an important factor of the residents' surgical results, ie, the earlier the first STCR of 60%, the better the surgical result.

Using the first STCR of 60% as a milestone, the residents' average surgical results, including both completion and complication rates, are compared in Table 3. Before the residents' first STCR of 60%, their overall completion rate was only 16.7% and complication rate was as high as 39.2%. While after that point, the average completion rate accelerated to 76.4% (16.7 *vs* 76.4%; $P<0.0001$) and complication rate decreased to 14.2% (39.2 *vs* 14.2%; $P=0.0033$). The learning curve of phacoemulsification among our residents was actually a 'theoretical' line constructed by tracing different residents' individual STCR in this study. Its pattern was similar to that of an exponential curve and the first STCR of 60% was the exponential point. Accordingly, we could classify each resident's current status of surgical skill into three different levels. For example, residents A–C were on the left side, residents D–I were in the middle, and residents J–K were on the right side of the learning curve.

Discussion

To the best of our knowledge, only one recent literature conducted by Dooley and O'Brien[16] had a comparable study on completion rate of resident-performed phacoemulsification. They measured subjective difficulty of each step of phacoemulsification performed by basic surgical trainees and found that nucleus emulsification and capsulorhexis were the two most difficult steps to

Table 2 The residents' individual surgical results of phacoemulsification

Resident (no. of cases, n*)*	*The residents' individual surgical results in each of their operation*[a]	*Completion rate (%) = (C + D)/*n	*Complication rate (%) = (B + C)/*n
A ($n = 14$)	BABAAABCABBADD	21.4% (3/14)	42.9% (6/14)
B ($n = 17$)	BABBADADAABBAADAA	17.6% (3/17)	29.4% (5/17)
C ($n = 15$)	DBADBBCBACAABDA	33.3% (5/15)	46.7% (7/15)
D ($n = 45$)	BBAABAABAADBABDCBAAA ABBBADADAAABAADDADDDDDDDD	33.3% (15/45)	26.7% (12/45)
E ($n = 17$)	ABAACAAABADADDADD	35.3% (6/17)	17.6% (3/17)
F ($n = 15$)	ABACAAABDADDDDD	46.7% (7/15)	20.0% (3/15)
G ($n = 13$)	AAAABBACDDDD	46.2% (6/13)	23.1% (3/13)
H ($n = 29$)	BAAABBAADDDDADDDDDDDBADDDDBDC	58.6% (17/29)	20.7% (6/29)
I ($n = 34$)	DAAABBABBACBDDDDDDDDDADDDDDDDDDDDD	61.8% (21/34)	23.5% (8/34)
J ($n = 13$)	BADADDDBDDDBC	61.5% (8/13)	30.8% (4/13)
K ($n = 14$)	BDDBDCDBDDBDDD	71.4% (10/14)	35.7% (5/14)
Total ($n = 226$)		44.7% (101/226)	27.4% (62/226)

[a]A = incomplete surgery due to supervisor's interference and without complications; B = incomplete surgery with either major or minor complications; C = complete surgery with minor complications; D = complete surgery without complications. The residents with first short-term completion rate of 40, 60 and 80% are underlined, shaded, and crossed out, respectively.

Table 3 Comparison of the residents' surgical results of phacoemulsification 'before' and 'after' their first short-term completion rate (STCR) of 60%

	Average completion rate	*Average complication rate*
Before STCR of 60%	16.7% (20/120)	39.2% (47/120)
After STCR of 60%	76.4% (81/106)	14.2% (15/106)

learn. Their residents' overall completion rate was 42.0%, similar to our results. In this study, we further measured our residents' complication rate in each step of phacoemulsification and found that their highest complication rate was also the steps of nucleus emulsification and capsulorhexis, despite the highest rate of supervisor's assistance in these two steps. This fact reflects not only a certain degree of difficulty to master but also a distinct property of small error margin in these barrier steps.

To help trainee surgeons overcome their barrier steps, some creative and innovative solutions have been suggested, such as practising in the lab, adopting a modular training model, and properly assessing surgical competency in the training programmes.[17–19] However, it was estimated by the programme directors that about 10% of the residents in the United States were still labelled as having trouble mastering surgical skills by the end of their residency.[20] Individual variation in surgical skill among residents of a same level was also a common problem in phacoemulsification training.[4] Therefore, knowing how to verify each resident's current status in his or her learning process is essential for the supervisors to arrange a timely and suitable adjustment of the training programme.

In this study, we were the first to demonstrate a pattern of phacoemulsification learning curve by using completion rate as a parameter. Further studies are necessary to verify its usefulness in assessing residents' surgical performance. Nevertheless, we suggest STCR of 60% to be a basic requirement for a resident to enter a true 'full-phaco' training course, during which the residents could be trained to further decrease the complication rate and to properly manage their complications. On the other hand, before STCR of 60%, their surgical training on cataract patients should be concentrated in overcoming the barrier steps.

The overall completion rate of our trainee surgeons was 44.7%, a relatively low rate for a senior resident. Although all our residents in this study had performed more than 50 'part-phaco' surgeries during their first 2-year residency, their surgical practices on the two barrier steps, capsulorhexis and nucleus emulsification, were apparently not enough. However, most of our residents could exceed the milestone of STCR of 60% during their residency training. In addition, after STCR of 60%, their completion rate was actually higher than 76.4% and their complication rate decreased with each successive case.[10]

A recent trend of decreasing resident surgical volume was reported to threaten the quality of phacoemulsification training.[18,21] Although a national survey of the programme directors in the United States revealed that 97% of their residents could complete at least 50 cataract surgeries by the end of the residency training.[22] Another national survey of the residents in the United Kingdom disclosed that only 42% of the senior house officers (SHOs) could meet the minimum requirement of 50 complete intraocular operations.[23] Except for a basic difference in the educational system

between these two countries, there seemed to be a disparity regarding the quantity of surgical training between the trainers and the trainees. One explanation for such disparity may be the difference in definition of a 'complete' surgery. Using our study as an example, the supervisors may regard all or most of the 226 patients as 'full-phaco' training cases. However, the residents or the SHOs might only count the 101 'complete' cases when calculating their surgical experience.

Recently, resident phacoemulsification learning curve was assessed with regard to total number of cases, with a break point of 80 cases identified.[24] The Residency Review Committee of the Accreditation Council for Graduate Medical Education has also increased the minimum number of cataract procedures performed by the resident from 45 to 86.[24] This change poses little problem for residents who could surpass an STCR of 60% at an early stage of their residency. However, for residents who had problems exceeding an STCR of 60%, this is a higher barrier. With a higher complication rate and a lower completion rate, such residents will have difficulty in accumulating enough cases in a patient-based practice and will enter a vicious cycle of phacoemulsification training. Thus, individual variations are common not only in surgical skill but also in surgical volume among residents of a same level. In such circumstance, we suggest residents, who could not exceed an STCR 60%, may need modular training instead of 'full-phaco' training to break the vicious cycle.

In summary, phacoemulsification is a challenging technique to learn and to teach due to its small margin of errors. Nevertheless, it is important for the supervisor not only to decrease the residents' complication rate, but also to increase their completion rate. We suggest the trainees' STCR to be a useful parameter to evaluate their surgical competency and STCR of 60% to be a basic requirement to achieve.

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