LUND UNIVERSITY

Validity and usability of a virtual reality intraocular surgical simulator

Selvander, Madeleine

2013

Link to publication

Citation for published version (APA):
Selvander, M. (2013). *Validity and usability of a virtual reality intraocular surgical simulator.* [Doctoral Thesis (compilation), Department of Clinical Sciences, Malmö]. Department of Clinical Sciences, Lund University.

Total number of authors:
1

General rights
Unless other specific re-use rights are stated the following general rights apply:
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.
• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal

Read more about Creative commons licenses: https://creativecommons.org/licenses/

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

VALIDITY AND USABILITY OF A VIRTUAL REALITY INTRAOCULAR SURGICAL SIMULATOR

Madeleine Selvander

Doctoral thesis

LUND UNIVERSITY
Faculty of Medicine

Malmö 2013

Department of Clinical Sciences Malmö, Ophthalmology

Department of Ophthalmology, Skåne University Hospital

Lund University, Sweden

© Madeleine Selvander and the respective publishers

Printed by Tryckeriet i E-huset, Lund University, Lund, Sweden

2013

Validity and usability of a virtual reality intraocular surgical simulator

ISBN 978-91-87449-18-5

To my family

"Experience is the name every one gives to their mistakes"

Oscar Wilde, *Lady Windermere's Fan, Act III*

TABLE OF CONTENTS

LIST OF PAPERS **9**

ABSTRACT **10**

THESIS AT A GLANCE **11**

BACKGROUND **12**

INCREASED DEMAND FOR INTRAOCULAR SURGERY 12

HIGHER DEMANDS FOR QUALITY CONTROL 12

INCREASED DEMAND FOR SAFE TRAINING OF ASPIRING INTRAOCULAR SURGEONS 15

MICROSURGERY AND STEREOACUITY 16

INVESTIGATING VALIDITY AND USABILITY OF A VIRTUAL REALITY INTRAOCULAR SURGICAL SIMULATOR **18**

1. INTRODUCTION TO THE STUDIES 18

1.1 Training of new surgeons *18*

1.2 Simulators for training of intraocular surgery *18*

2. AIM OF THE THESIS 20

3. MATERIAL AND METHODS 21

3.1 Eyesi intraocular virtual reality surgical simulator *21*

3.2 Simulator film evaluations *23*

3.3 Participants in the studies *24*

3.4 Stereoacuity *24*

3.5 Statistical analysis *24*

4. RESULTS AND DISCUSSION 25

4.1 Results and Discussion paper I: Evidence for construct validity and concurrent validity *25*

4.2 Results and Discussion paper II: The surgical performance improves with training, evidence for concurrent validity of the capsulorhexis procedure *28*

4.3 Results paper III: The simulator scoring system needs improvement for hydromaneuvers and phaco divide and conquer modules *34*

4.4 Results and Discussion paper IV: Performance correlates with level of stereoacuity. No sex difference *35*

OVERALL DISCUSSION - SIMULATOR TRAINING CAN REPLACE SOME OF TODAYS TRAINING ON PATIENTS **40**

STUDY RESULTS 40

INDIVIDUALIZED TRAINING 41
THE STRUCTURE OF TRAINING – COMPETENCE BASED CURRICULUM 41

CONCLUSIONS 43

POPULÄRVETENSKAPLIG SAMMANFATTNING 44
BAKGRUND VALIDERING OCH ANVÄNDBARHET AV SIMULATOR FÖR TRÄNING AV ÖGONKIRURGI 44
Ökad efterfrågan av ögonoperationer 44
Högre krav på kvalitetskontroll 44
Ökade krav på säker träning av blivande ögonkirurger 44
INTRODUKTION TILL STUDIERNA 45
Träning av blivande kirurger 45
Simulatorer för träning av ögonkirurgi 45
Ögonsimulatorn Eyesi 46
SYFTE 46
RESULTAT: SIMULATORTRÄNING KAN FÖRBÄTTRA KIRURGISK FÖRMÅGA FÖR BLIVANDE ÖGONKIRURGER 47
Kirurger presterar bättre än icke-kirurger i Eyesi (I) 47
Det går att träna upp den kirurgiska förmågan i Eyesi (II) 47
Videobedömningar säkrare än simulatorns poängsystem (III) 48
Prestationen korrelerar med stereoseendet – ju sämre stereoseende desto sämre prestation. Ingen skillnad mellan män och kvinnor (IV) 48
BETYDELSE: TRÄNING I SIMULATOR KAN ERSÄTTA DAGENS TRÄNING PÅ VERKLIGA PATIENTER 49

ACKNOWLEDGEMENTS 51

REFERENCES 53

APPENDICES 65

LIST OF PAPERS

This thesis is based on the following papers. In the text they are referred to by their roman numeral (I – IV):

I

Selvander M, Åsman P. Cataract surgeons outperform medical students in Eyesi virtual reality cataract surgery: evidence for construct validity. *Acta Ophthalmol. 2012 Jun 7. doi: 10.1111/j.1755-3768.2012.02440.x.*

II

Selvander M, Åsman P. Virtual reality cataract surgery training: learning curves and concurrent validity. *Acta Ophthalmol. 2012 Aug;90(5):412-7*

III

Selvander M, Åsman P. An evaluation of Eyesi surgical simulator as assessment tool for cataract surgical skill. Human reader better and show an improvement potential in computer scoring. *Manuscript.*

IV

Selvander M, Åsman P. Stereoacuity and intraocular surgical skill: effect of stereoacuity level on virtual reality intraocular surgical performance. *J Cataract Refract Surg. 2011 Dec;37(12):2188-93*

ABSTRACT

Cataract surgery is one of the most common surgical procedures in Sweden and around 90 000 operations are made each year. An aging population with increased demands on quality of life and good visual acuity, has led to an increased rate of surgery and more surgeons needs to be trained. Training of new cataract surgeons is done on scarce wet-lab training but mainly on patients. Training is costly and complications are higher for new surgeons compared to experienced ones. In the airline industry simulators are used for training. Pilots have to prove competent before flying a new airplane. No such standards exist for new cataract surgeons.

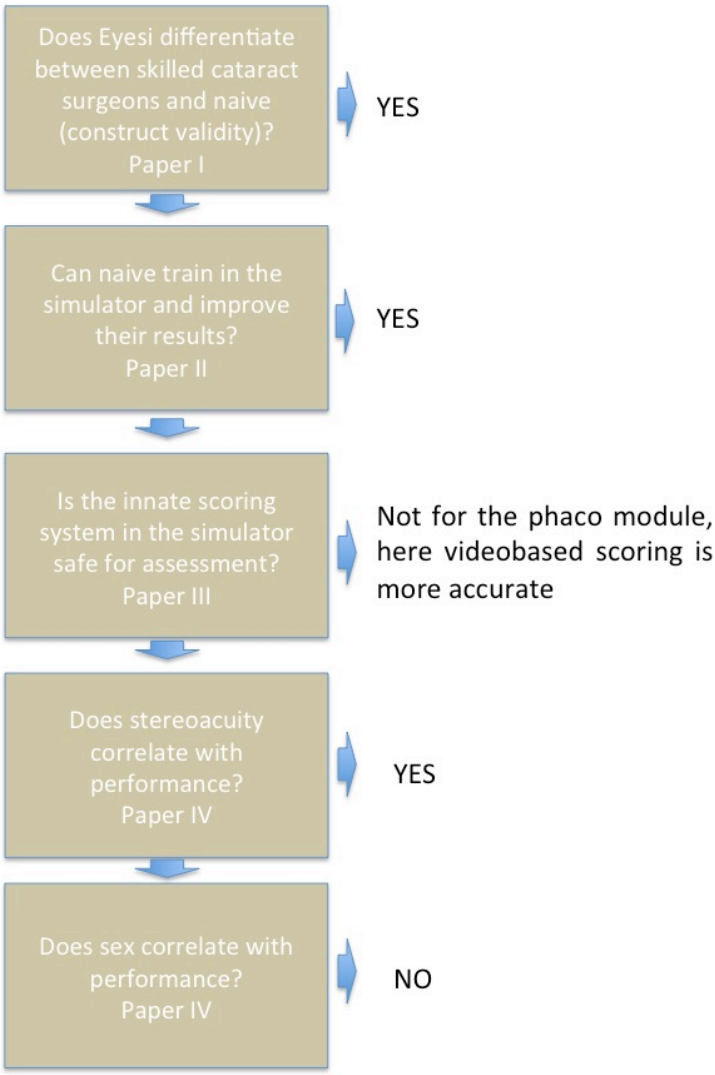
Surgical simulators have been used in other surgical fields for training and reports have shown that training has improved performance on real operations. The purpose of this work was to validate Eyesi, a surgical simulator for cataract surgery training, and analyze learning curves. Furthermore we set out to investigate whether factors like stereoacuity and sex would be important for performance in the simulator.

Evidence for construct validity was found for cataract specific modules capsulorhexis, hydromaneuvers and phaco divide and conquer and for manipulating modules cataract navigation training, cataract forceps training and cataract cracking and chopping training. Analysis of learning curves showed significant improvement throughout training. Evidence for concurrent validity was established for the capsulorhexis module. For the hydromaneuvers and phaco modules, the innate simulator scoring could not distinguish surgical skill but discrimination was dependent on video based human scoring.
Stereoacuity was found to correlate with performance on the simulator but there were large individual variations. An individual's sex had no influence on performance.

We have shown that Eyesi can differentiate cataract surgical skill and that naïve can train in the simulator and improve. Stereoacuity has an effect on performance but there were large individual variations. Simulation-based training has the potential to move the early learning curve out of the operating room.

Keywords: simulator, cataract surgery, learning, training, Eyesi

THESIS AT A GLANCE



BACKGROUND

INCREASED DEMAND FOR INTRAOCULAR SURGERY

Intraocular surgery has experienced a tremendous technical development that has led to beneficial results for patients. From treating retinal detachment conservatively to high technology vitrectomy leading to 80-90 % healing with one operation[1]; from large incision cataract surgery without intraocular lenses to millimeter incision phacoemulsification surgery[2,3] with multifocal lenses making patients spectacle independent[4,5]. Cataract surgery, an operation where the lens is exchanged with an intraocular plastic lens, is one of the most common operations in Sweden today. An aging population[6] with increased demands on quality of life and good visual acuity at all ages in life, has led to more people being operated[7] and being operated at an earlier stage in their cataract development[8]. The result is, an increase in rate of surgery from 4,5 to 9 per 1 000 inhabitants from 1992 to 2009[8], and patients being operated at a younger age[8]. In Sweden around 90 000 cataract operations are performed each year[7].

HIGHER DEMANDS FOR QUALITY CONTROL

The clinical competence of surgeons is a matter of public concern. Since the beginning of the 90s, several quality registers have been established to assure quality benchmark for surgical procedures[9]. Since 1992, the Swedish cataract register has been used to follow surgical quality parameters and complication rates associated with cataract surgery. Pressure from government regulatory bodies[10] as well as public advocacy has focused the attention on quality of surgical procedures. Complications during and after cataract surgery are costly and harmful for patients; posterior capsular rupture during cataract surgery leads to highly increased risk for retinal detachment and deficient postoperative visual acuity[11].

The cataract surgical procedure

Cataract surgery is performed in local anesthesia and the operation is done under a microscope. Millimeter large incisions are made to let instruments enter the eye. Viscoelastics is injected into the eye to keep the anterior chamber stable. A microforceps or a cystotome is used to create a flap on the anterior capsule of the lens. The forceps is used to pull the flap and create a round opening in the capsule, the capsulorhexis (Fig. I). Hydrodissection is performed by injecting fluid between the lens and the

capsule to make the lens mobile and movable in the capsule (Fig. II). By using phacoemulsification energy, the lens is divided into smaller parts and consumed with the probe (Fig. III). The lens capsule is cleaned with an irrigation and aspiration device and the lens is thereafter inserted into the capsular bag. All remaining viscoelastics is removed before the incisions are hydrated and made tight sealed.

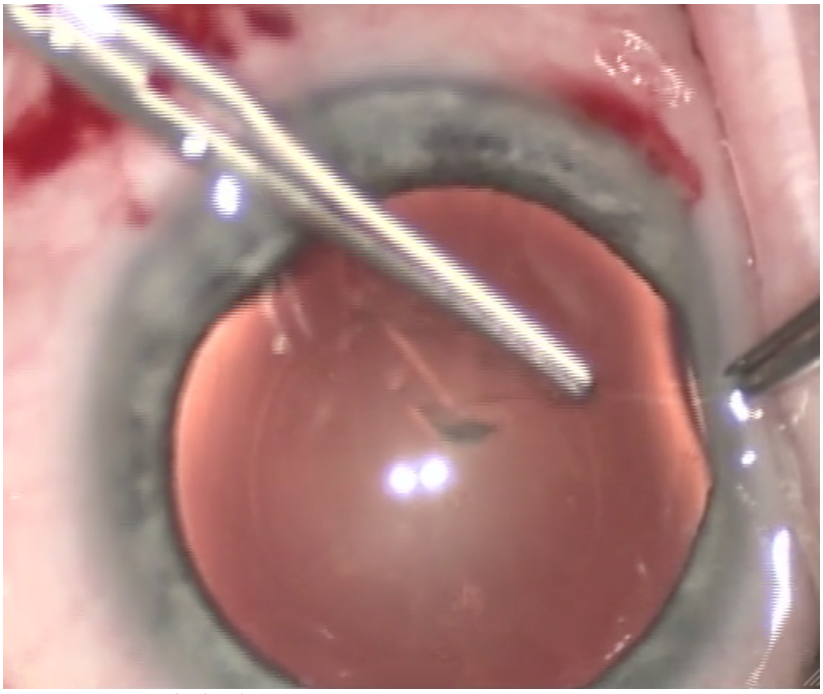


Figure I. Capsulorhexis

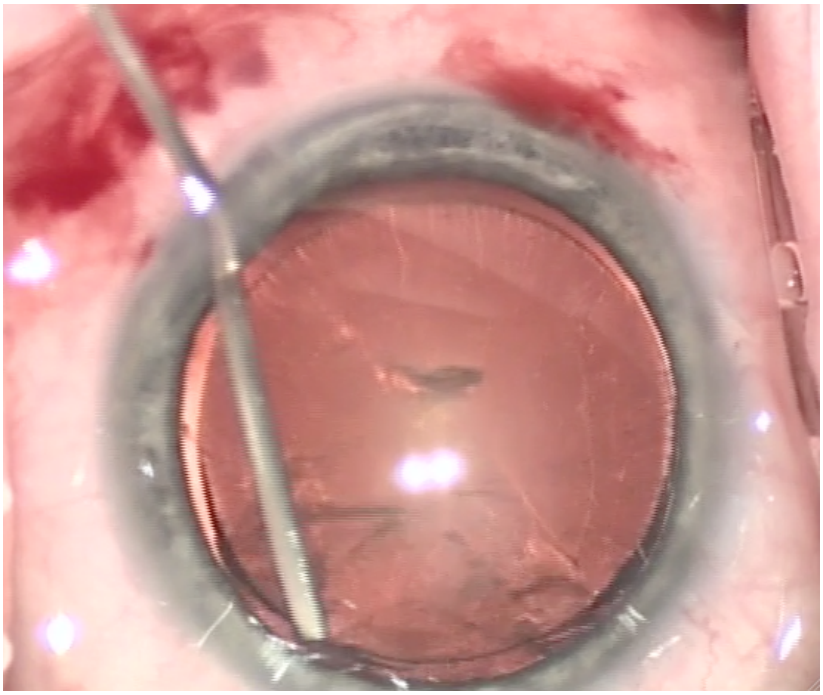


Figure II. Hydrodissection

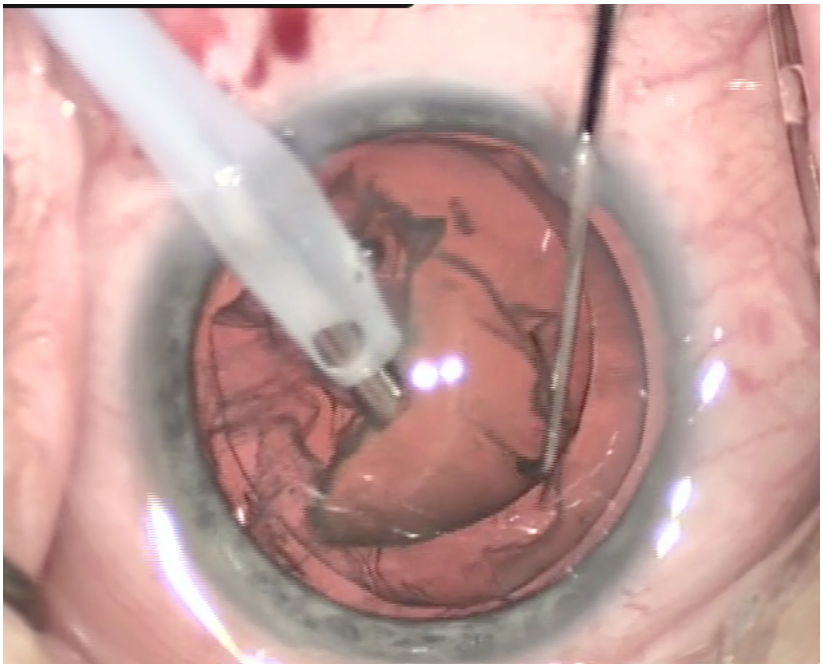


Figure III. Phacoemulsification

INCREASED DEMAND FOR SAFE TRAINING OF ASPIRING INTRAOCULAR SURGEONS

More operations being performed leads to an increased need for training of new eye-surgeons. At present, an estimated number of 30 surgeons are under training for cataract surgery in Sweden today. In the aviation industry, pilots are trained in simulators before flying new airplane models. They are evaluated in several steps and have to prove proficiency before flying new air planes[12]. Airline simulators play an important part in this training[12]. Such a standard does not exist for new intraocular surgeons[13]. Training of aspiring surgeons is time consuming and the risk for complications such as posterior capsular rupture, are considerably higher for new cataract surgeons compared with experienced ones[14,15]. Cataract surgeons under training also show a less efficient operative technique and use more phacoemulsification energy[14]. Phacoemulsification energy has a negative effect on the corneal endothelium[16]. These facts altogether makes it preferable to move the learning curve for new eye-surgeons out of the operating room[17].

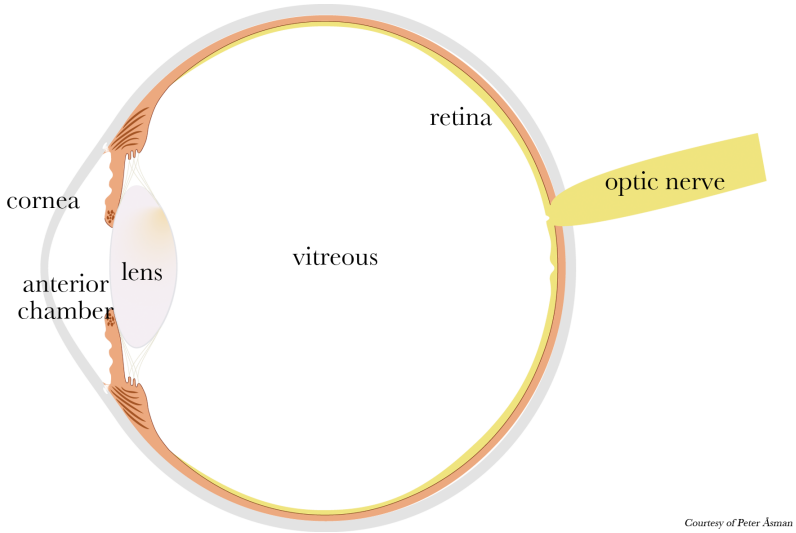


Figure IV. The anatomy of the eye

Training of new surgeons has traditionally taken place via a master-apprentice model. The apprentice has learned by being instructed by a master and the master has been the guarantee for appropriate learning and progress being made. Disadvantages with this type of training[18,19] and demands from the American Accreditation Council for Graduate Medical

Education[20] has advocated a focus on competence in surgical training. In all, there is a trend and ambition to move towards a more competency based curriculum[21,22] instead of the master-apprentice model.

MICROSURGERY AND STEREOACUITY

It might be considered intuitive that a good feeling of depth would be advantageous in microsurgery. Stereoacuity is not the same as feeling of depth though. To sense depth, monocular depth cues such as shadows, linear perspective, gradient and texture play a role[23,24]. Binocular depth cues such as accommodation and convergence can also be used to determine whether and object is close or far away[24]. Stereoacuity develops in early infancy and is fully developed at the age of 5-7 years[23]. Stereoacuity of 30-40 sec of arc is regarded normal[23]. Stereopsis decreases with age and of individuals over 65 years, only a quarter have normal stereoacuity[25].

Several methods exist for measuring stereoacuity. Standard plates such as Titmus, Frisby and TNO are frequently used but computer-based procedures are sometimes also applied in studies[26]. Random dot stimuli are regarded as "gold standard" for measuring stereoacuity[27]. In studies using several different stereoacuity measurements, TNO usually receives the highest thresholds compared to other tests[27,28]. TNO is a random dot test where red-green glasses are used to separate the images presented to each eye. It contains no contour specific information in the picture and the stereotarget is not visible by monocular visible contours. This is considered to be the explanation for TNO being more difficult compared to for example Titmus[27].

In a British cohort, the prevalence of deficient stereoacuity defined as above 40 sec of arc was 14%[29]. In a study by Rawlinson et al. investigating the stereoacuity threshold levels among dental students, they found that 26% of students had a stereoacuity threshold level above 60 seconds of arc[30]. As mentioned above, stereoacuity is diminished in older individuals but again this effect is most marked using TNO stereoacuity test[27]. It is suggested that this might be because of a failure to obtain and maintain fusion rather than a true loss of stereopsis[27].

It is known that stereoacuity is of value for humans especially in near vision and where complex hand-eye coordination is involved[23]. The function of vision is measured on applicants for several professions involving public safety (pilots, police officers, sea captains, fire fighters). No such visual standard exists for screening professionals in medicine but there is a positive attitude towards visual screening[31]. In a survey, 80% of ophthalmologists felt that there was a need for screening of new candidates

for residency[31]. Some countries do have restrictions for their eye doctors; in the Czeck Republic normal stereoacuity is mandatory for becoming an intraocular surgeon, and in the Netherlands stereoacuity is measured on all residents before entering into ophthalmology. The scientific base for such exclusions in ophthalmology is not fully investigated though.

Several studies have elucidated the effect of stereoacuity on motor skills. Amblyope children have been found to perform poorer than control subjects on some fine motor skills[32]. On a dexterity test, Murdoch et al. found that normal individuals performed better than those with no stereoacuity[33]. Other studies have investigated the motoric skills of grasping and catching, where bad stereoacuity makes grasping objects more difficult[34] and where the success of catching a ball is favorable for those with normal stereoacuity[35]. In the latter study they also saw that with training, there was no improvement for those individuals with bad stereoacuity.

In surgical training studies have shown that individuals with deficient stereoacuity perform worse than normal subjects on basic laparoscopic skills training[36,37] and that the difference remained also after training[37]. Having found these results on fine motor tasks one would expect that working with microscope would be more difficult for individuals with deficient stereoacuity. However, Grober et al did not manage to show a correlation between the level of stereoacuity and performance on a microsurgical skills task[26].

Initial data has shown that strabismic patients with bad or no stereoacuity performed worse than normal controls on an intraocular surgical simulator[38], but if there is a correlation between level of stereoacuity and performance is not known. Also, a study by Rossi et al showed that individuals with better stereoacuity performed better on the same intraocular surgical simulator training device for the posterior segment[39]. A confounding factor in their study though was that the vitreoretinal surgeons also had better stereoacuity.

INVESTIGATING VALIDITY AND USABILITY OF A VIRTUAL REALITY INTRAOCULAR SURGICAL SIMULATOR

1. INTRODUCTION TO THE STUDIES

1.1 TRAINING OF NEW SURGEONS

Training of new intraocular surgeons is costly and time consuming[40]. Learning cataract surgery demands well-developed psychomotor skills and data shows that around 10% of aspiring surgeons have difficulties in acquiring surgical skills[22]. Development of surgical training programs in ophthalmology is still in an early phase and only a few have been published[41-44]. Validated detailed programs for follow up of improvement of post-operative results on an individual base, are rare[45]. Assessment of trainees in intraocular surgery training is still in its early stages[13,46-49] and only few assessment tools have been thoroughly validated[50-53]. Furthermore, validation of training programs is incomplete[13,54]. Today, training takes place on scarce wet-lab training occasions[42,55-58] but mainly the training is done in the operating room on real patients[59,60].

Capsulorhexis (where the anterior lens capsule is opened) and phacoemulsification (where ultrasonic energy is used to fragment the opaque lens into smaller pieces and with vacuum remove the pieces out of the eye) are the two procedures in a cataract operation that most trainees find difficulties in handling[61]. For surgical training to be efficient, it has to focus training on improving difficult parts[62]. The psychologist Ericsson has studied individuals that on different areas possess a high level of expertise. What they all have in common is that they have sacrificed an enormous amount of time to deliberate practice. For training to be efficient, it also needs to be distributed in time[63,64]. Surgical simulators provide possibilities of deliberate and distributed training. They are easy to use without tedious preparations and set-up lead times. Specific parts of an operation can be trained intensely without limitations. Performance can be assessed and progress can be measured. Lack of progression can call for intervention, and performance can be compared with previously set target criteria and not with peers.

1.2 SIMULATORS FOR TRAINING OF INTRAOCULAR SURGERY

Surgical simulators have been used in other surgical fields for training and reports have shown that training has improved performance on real

operations[65-67]. Simulators for intraocular surgery is still in an early phase of development[68] even though some systems have been presented[39,69-72]. For intraocular surgery, two commercially available virtual reality simulators have been presented; Eyesi (VRmagic, Germany) and PhacoVision (Melerit, Sweden). PhacoVision is a simulator for training of cataract surgery[73]. Eyesi is a simulator with possibilities to train both cataract surgery and posterior segment surgery [39,74-76]

For a surgical simulator to be included into a training curriculum, it needs to be evaluated for how well it imitates the reality it should simulate, "construct validity". It is usually measured by comparing performance between individuals with different surgical experience. How well a simulator scoring measures the performance is called "concurrent validity". This is examined by comparing the simulator evaluation system with another already used method for evaluation.

For the Eyesi simulator, initial reports have shown construct validity for capsulorhexis (where the anterior lens capsule is opened)[76,77] but no reports have investigated other procedural modules in the simulator. Furthermore, the learning curves for these modules have not thoroughly been investigated. No studies have addressed concurrent validity.

Individuals learn at different pace and have different innate abilities when training starts. Sex is said to be one factor that affect surgical simulator training[78] whereas other reports have shown no such differences[79,80]. As shown above, stereoacuity has also been considered as a factor to influence surgical skill. Initial data has shown that strabismic patients with bad or no stereoacuity performed worse on an intraocular simulator[38], but if there is a correlation between performance and level of stereoacuity is not known. Previous video-game experience and visuospatial ability are additional factors that have been reported to influence surgical performance[78,81-83] but their role in intraocular surgical training is unknown.

2. Aim of the thesis

- To investigate construct validity of Eyesi, a simulator for training of intraocular surgery
- To investigate concurrent validity of Eyesi modules
- To investigate learning curves on Eyesi for specific modules
- To investigate factors that can influence performance of intraocular surgery using an intraocular surgery simulator

3. Material and Methods

3.1 Eyesi intraocular virtual reality surgical simulator

For the purpose of this study, the Eyesi simulator for intraocular surgery was used. The simulator consists of a mounted eyepiece on a mannequin head. There is one head for training for cataract surgery, and one head for training of vitreoretinal surgery. Instruments or "probes" are inserted into the eye and cameras inside the eye detect the movements of the probes. The movements are processed in a computer and a three dimensional stereoscopic image is projected on two oculars mimicking a real operations microscope. The same image is also shown on an observer screen (Fig. V).

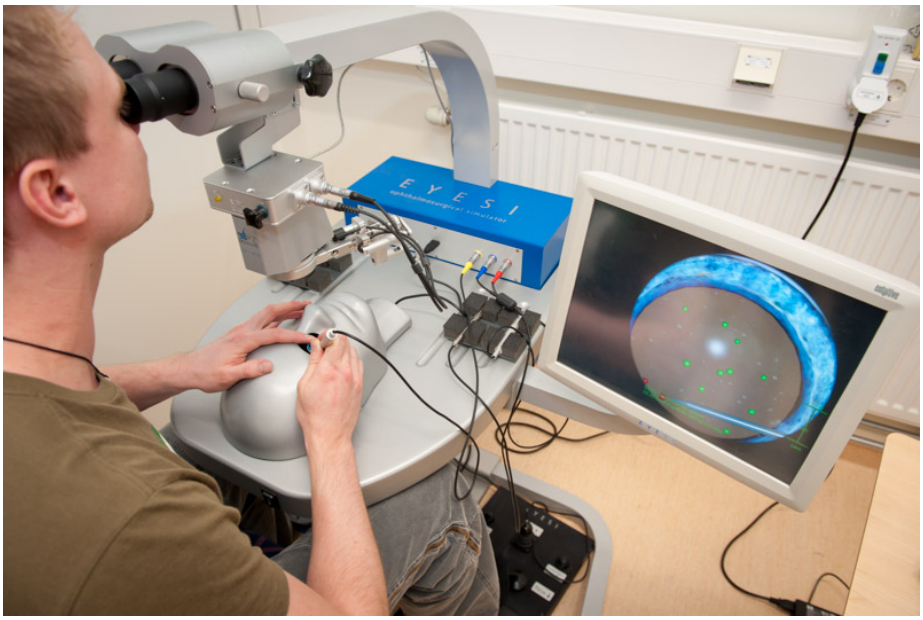


Figure V. Student training in the Eyesi surgical simulator.

Several different training modules are available for each of the two simulator heads. The modules are both procedure specific modules for cataract surgery and vitreoretinal surgery, and manipulating modules for the two different types of surgery. Furthermore, each module is also available in different levels of difficulty. The modules used in this study are presented in table I and shown in fig. VII and VIII.

Table I. Description of anterior chamber modules

Module	**Level**	**Description**	**Used in paper**
Capsulorhexis	1 4	A flap is already present. The trainee has to form and complete a capsulorhexis The trainee has to inject viscoelastics into the anterior chamber and create a flap and form a capsulorhexis.	IV I, II, III
Hydromaneuvers	1	The trainee places a cannula under the rhexis edge and injects liquid solution in order to create a visible fluid wave in the cortex. Afterwards, the trainee rotates the nucleus proving that an appropriate hydrodissection has occurred.	I, III
Phaco divide and conquer	5	The trainee has to create groves in the nucleus, crack the nucleus into quadrants, and finally consume the quadrants with ultrasonic energy using phacoemulsification.	I, III
Cataract forceps training	3, 4	With forceps, the trainee has to move small triangles into a fictive basket. When put in place, the triangles turn green.	I, IV
Cataract navigation training	2, 3	The trainee has to hold a probe still inside of spheres until it turns green (1-2 sec). The spheres are scattered at different levels in the anterior chamber.	I, IV
Cataract cracking and chopping training	6	The trainee has to pull each end of a handle simultaneously thereby elongating it into a given length.	I

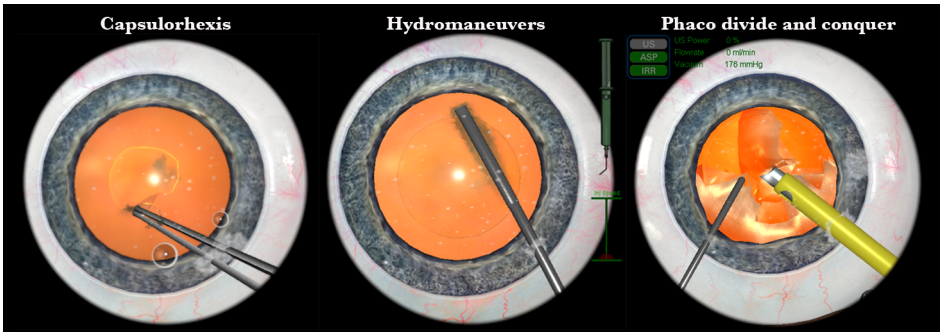


Figure VII. Procedure-specific modules: capsulorhexis, hydromaneuvers and phaco divide and conquer.

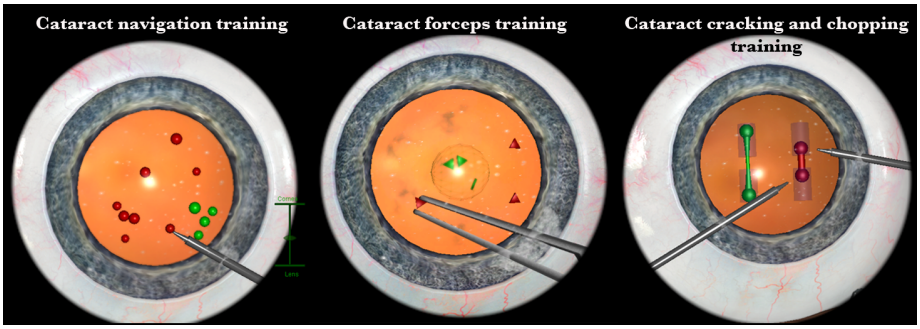


Figure VIII. Manipulating modules: cataract navigation training, cataract forceps training and cataract cracking and chopping training.

Video clips from procedure-specific modules can be seen on http://www.eyesifilmer.eyelearn.se.

For each task, the simulator calculates a performance score between 0 and 100 as a judgment of how well the task was performed. The score is a sum of several parameters that reflects performance of to what extent the task was accomplished, how the instruments were handled, time efficiency, tissue damage and microscope usage. Several performance based parameters can be achieved afterwards in an excel spreadsheet but how the overall score is calculated is not fully disclosed by the manufacturer.

3.2 Simulator film evaluations

Recorded of performance on modules capsulorhexis, hydromaneuvers and phaco divide and conquer were evaluated with regard to cataract surgical skill in paper I, II and III. The recorded video clips were anonymously analyzed with the Objective Assessment of Cataract Surgical

Skill (OSACSS) tool[50] in applicable parts and modified Objective Assessment of Surgical Skill (OSATS) tool[84]. OSACSS is a procedure specific evaluation tool where different parts of a cataract operation is evaluated and given a score of 1 to 5 based on the performance. The OSACSS has been used in real cataract operations and has been shown to differentiate different levels of cataract surgical skill[50]. OSATS is a general video-based assessment tool that has been used in real operations, laparoscopic surgery[67,85] as well as in ophthalmic microsurgery[86], and has been shown to differentiate surgical skill. OSATS involves judgments regarding precision of operative technique, tissue handling, economy and confidence of movements. Two experienced cataract surgeons who were masked regarding the subjects' identity evaluated the procedures.

3.3 Participants in the studies

The cataract surgeons in paper I and III have been recruited among practicing surgeons in the local hospital and in the region. They have all given informed consent. Their experience ranged from 15 to over 10 000 operations.

The medical students in the studies were recruited during their ophthalmology rotation on the clinic. The simulation session is part of a mandatory session but the students' participation in the studies was voluntarily.

None of the study participants had previous experience with the Eyesi surgical simulator.

3.4 Stereoacuity

In paper II and III information regarding study participant's stereoacuity was presented. Threshold stereoacuity was measured using TNO chart plates V to VII (Lameris Ootech BV).

3.5 Statistical analysis

Differences in performance parameters between surgeons and medical students in paper I were tested for statistical significance using the Mann–Whitney U-test. Spearman correlation test was used to analyze correlation between the OSACSS and OSATS video scores and the overall score given by the surgical simulator. Intraclass correlation coefficient was used to determine interrater reliability for the OSACSS and OSATS scoring.

Friedman test was used to analyze learning curves in paper II. Also Wilcoxon signed ranked test was used to compare scores between first and

tenth iteration. Mann-Whitney U-test was used to compare performances between group A and B. Again Spearman correlation test was used to analyze correlation between the OSACSS and OSATS video scores and the overall score given by the surgical simulator.

In paper III ROC curves were plotted and the areas under the curves were compared using an algorithm suggested by DeLong, DeLong and Clarke-Pearson[87]. Interrater reliability was analyzed with intraclass correlation coefficient.

Performance parameters were correlated to level of stereoacuity with Spearman correlation test. For comparisons of performance between men and women, Mann-Whitney U-test was used.

4. Results and Discussion

4.1 Results and Discussion paper I: Evidence for construct validity and concurrent validity

In this paper we decided to investigate construct and concurrent validity of the Eyesi anterior segment cataract surgical simulator. Performance scores were compared between surgeons and medical students. Cataract surgeons received higher simulator scores than naïve on capsulorhexis (Fig. IX), cataract navigation training, cataract forceps training and cataract cracking and chopping training. Analysis also revealed that naïve made more tissue damage on the cornea (capsulorhexis, $p = 0.048$; cataract forceps training, $p = 0.021$) and lens (cataract cracking and chopping training $p = 0.048$). These findings are in accordance with previous studies demonstrating construct validity for capsulorhexis[76] and cataract forceps training[74]. In the latter study they also showed that surgeons made less damage to the cornea, which are findings also supported in our study. In addition we could show evidence for construct validity based on overall score for several modules not previously investigated: manipulating modules cataract navigation training and cataract cracking and chopping training.

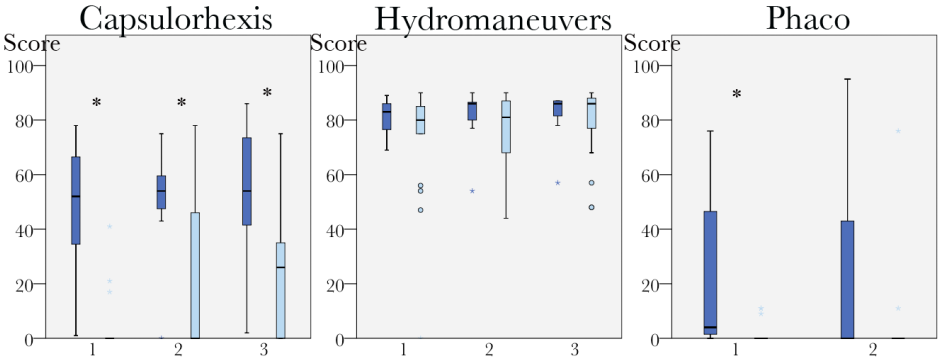


Figure IX. Boxplot of overall scores for cataract surgeons (dark blue) and naive (light blue) during training in modules capsulorhexis, hydromaneuvers and phaco divide and conquer. Median= thick horizontal line, boxes = 25 and 75% percentiles, whiskers = min and max.

On the hydromaneuvers and phaco divide and conquer modules, the overall score did not differ between the two groups and we could notice disappointingly low simulator scores for surgeons on the phaco divide and conquer module. (Fig. IX).

The second iteration on capsulorhexis, hydromaneuvers and phaco divide and conquer was also - recorded and evaluated with OSACSS and OSATS tools. The video scores were compared between surgeons and naïve. Surgeons received significantly higher video scores compared to naïve thus showing evidence for construct validity also for the two latter modules (Fig. X).

The video scoring (OSACSS) correlated well with the computer based overall scores for capsulorhexis ($r=0.669$ $p<0.0001$) but only moderately for hydromaneuvers and phaco divide and conquer ($r=0.525$ $p=0.010$, $r=0.566$ $p=0.004$ respectively). Also the OSATS score correlated significantly with the sum of overall score for the three modules above ($r=0.657$ $p=0.001$). Because the OSACSS video evaluation tool has demonstrated construct validity for video-based evaluations of real cataract operations[50], it strengthens the concurrent validity of the scoring

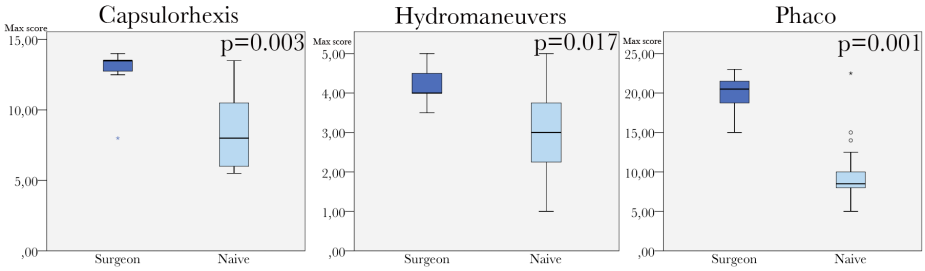


Figure X. Comparison between cataract surgeons (dark blue) and naive (light blue) during second iteration of capsulorhexis, hydromaneuvers and phaco divide and conquer measured by OSACSS. Median= thick horizontal line, boxes = 25 and 75% percentiles, whiskers = min and max.

system in the simulator for the capsulorhexis module where the correlation was high. For hydromaneuvers and phaco divide and conquer, the correlation was only moderate and poses questions regarding the innate simulator scoring.

A shortcoming in our study is that it does not include residents. One could argue that residents possess surgical cognitive knowledge that medical students do not have. So, in that case, it could be possible that the differences exposed between surgeons and naïve represented by medical students would at least partly constitute of cognitive knowledge differences rather than manual surgical skills. To overcome these discrepancies we recruited the students during their ophthalmology rotation. Before the training started, they received information regarding important structures of the eye and were thoroughly informed of important structures and important parts of the procedures. Before each new module was commenced, they were all shown voice-guided instructional videos where important aspects were pointed out. As a comparison Le et al[77] did show a correlation between ophthalmic experience and total score on two manipulating modules (forceps and anti-tremor modules) where they showed that medical students performed worse than the other groups including residents and staff. However, their most junior group of residents had performed 0-15 cataract surgeries and also several of them had previous experience with the Eyesi simulator making this group not representative of non-surgically experienced residents.

We did use a non-parametric approach when analyzing the data. The simulator overall scores were truncated and not normally distributed

regarding overall score for the naïve group in modules capsulorhexis and phaco divide and conquer and thus not appropriate for a parametric statistical analysis. For hydromaneuvers the parametric approach could have been used but we decided to treat data consistently between the different modules thus using non-parametric statistics for a all analyses.

4.2 Results and Discussion paper II: The surgical performance improves with training, evidence for concurrent validity of the capsulorhexis procedure

The purpose of this study was to investigate learning curves on two modules, cataract navigation training and capsulorhexis. Furthermore, we wanted to investigate whether training in one module affected performance on the other, and study the concurrent validity of capsulorhexis. As a pilot study, students' level of stereoacuity was also measured.

The modules used in this study were chosen for being one manipulating module and one procedure specific module. For the manipulating module cataract navigation training, a plateau was reached already after three iterations regarding overall score (Fig. XI) and the students reached surgeon proficiency levels (Paper I) indicating a rapid learning, something that has been found in other surgical simulators as well[88]. For capsulorhexis, the overall score learning curve did not reach a plateau (Fig. XI) and the levels were far from the scores of surgeons (54, Paper I). Being a different simulator software version used in paper I, the results are not completely comparable, but gives a hint of what level to strive for. Capsulorhexis is considered to be one of the most difficult steps in a cataract operation for new surgeons to master[61] so it is not surprising that more than ten iterations would be needed to capture this skill. Furthermore, ten iterations on the same level of difficulty might not be the optimal training schedule. Gradually increasing difficulty might be a better approach[89].

As shown in paper I, one of the differences found between naïve and skilled surgeons was that the naïve made more damage to intraocular structures such as the corneal endothelium and the lens. In laparoscopic operations it has been shown that tissue damage on real operations was less likely to occur in a VR-trained group[65]. In our study, with training, the students learned how to handle instrument with more caution and efficiency leading to less injuries to cornea and lens. This indicates that the simulator might be part of early training of new cataract surgeons.

Training in one module did not significantly affect score in the other showing that training improves somewhat different skills.

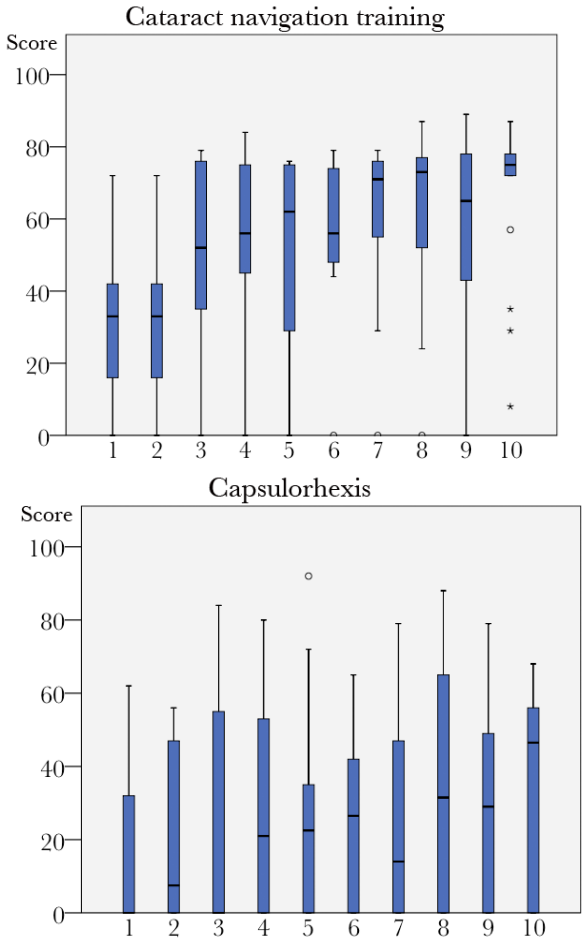


Figure XI. Learning curves for overall score for cataract navigation training and capsulorhexis. Median= thick horizontal line, boxes = 25 and 75% percentiles, whiskers = min and max.

Evidence for concurrent validity was found for capsulorhexis ($r= 0.704$, $p < 0.0001$).

Looking into detail at each individual' overall score learning curve for cataract navigation, one could notice that skills at baseline vary between individuals. We could see that some individuals showed improvement

during the training, others performed good at baseline and therefore did not improve considerably. Yet others showed generally low scores with no improvement or a few scores with good results and after that no improvement or even stagnation. This might be due to pure luck with one or two iterations or maybe they were just slow learners and ten iterations might not be enough for them to excel. For a couple of individuals, exhaustion was seen at the end of the training. The training took place during one session that lasted one hour and for a non-trained individual that could be a long time to train without a pause.

Grouping of individuals based on their learning curves has been considered. Curve fitting is one statistical model to illustrate and quantify learning. In our case, using a linear curve is not appropriate since it has no limit or plateau. The same is true for a logarithmic or power curve. An inverse curve and an S-curve have plateaus and slopes. We decided to use a non-linear regression model with an inverse curve ($y=a-b/x$) to fit with our learning curves. Thereby, it would be possible to characterize each individual's learning curve by two figures: the asymptote (where the end training would aim at) and the slope (the rate of progression)[90]. In our curve "a" would represent the asymptote and "b" the slope. Applying this approach to the learning curves for overall score of cataract navigation training gave a reasonable curve fit for six of the 17 curves with $r2>0,35$ (Fig. XII).

Another approach to handle learning curves is to try to group individuals based on their performance throughout training. Schijven et al grouped their individuals into four categories based on their innate abilities and gain through VR training[91]. Using the same approach and grouping of individuals based on their learning curves on the cataract navigation training module overall score is shown in table II and fig. XIII. The four respective groups are also marked with colors in fig. XII.

For capsulorhexis, the overall scores showed a similar pattern as for cataract navigation training with a lot of individual variations. Some learning curves showed incremental improvement whereas other curves did not improve or showed inconclusive improvement. Also here was an exhaustion phenomenon seen for three individuals. Looking at the scores

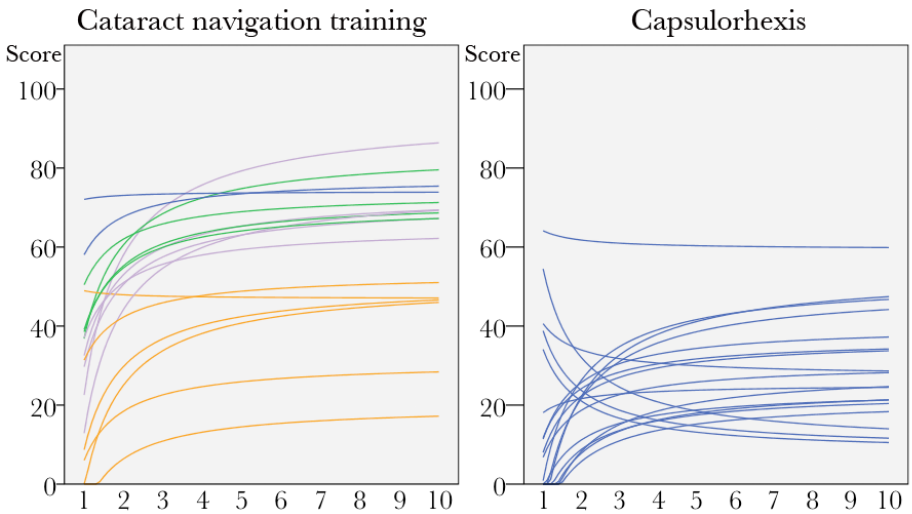


Figure XII. Individual learning curves using curve fit with inverse curve.

throughout the iterations, a blunt scaling rendering many iterations 0 score is noticeable. As is seen in paper I, this raises questions regarding the perfection of the scoring parameter overall score in the simulator. Comparing with the videoscoring, there was decent correlation between the simulator score and the OSACSS video-based score, but as also seen in paper III, the video-based score was more accurate in detecting surgical skill for the capsulorhexis (ROC area 0,887 compared to for 0.761 simulator innate score) pointing towards an improvement potential in the scoring for the capsulorhexis module.

Trying to group individuals based on their innate abilities and gain with VR training using the overall score is difficult and not meaningful due to the nature of the scoring (blunt scaling, imperfect scoring). Comparing the learning curves to inverse and S, only 2 of the 18 curves significantly fitted to a curve. Again, this is judged to be due to an innate insufficient scoring and not due to a non-existing learning. Overall, the inverse curve gave the best fit (8 out of 18) for the group as a whole (Fig. XII).

Our study subjects all took a stereoacuity test. We could se a trend in difference between individuals with normal and subnormal stereoacuity in performance scores on the simulator working favorable for those with normal stereoacuity. These results lead to the initiation of the study presented in paper IV.

Table II. Grouping of individuals based on their performance on cataract navigation training.

Group	Group description	Profile description	Participants	%
1 (blue)	High level of innate abilities, gaining little extra improvement	mean score >70, SD<13.2	6, 8	12
2 (green)	Moderate levels of innate abilities, gaining improvement	mean score 60-70, SD 13.3-15	3, 4, 11, 15	24
3 (pink)	Moderate levels of innate abilities, gaining some improvement	mean score 50-73, SD >15, all last three iterations >30	1, 2, 7, 10, 14	29
4 (orange)	Low levels of innate abilities, improvement not demonstrated	mean score 0-49. SD>15, one or more of last three iterations <30	5, 9, 12, 13, 16,17	35

SD=standard deviation

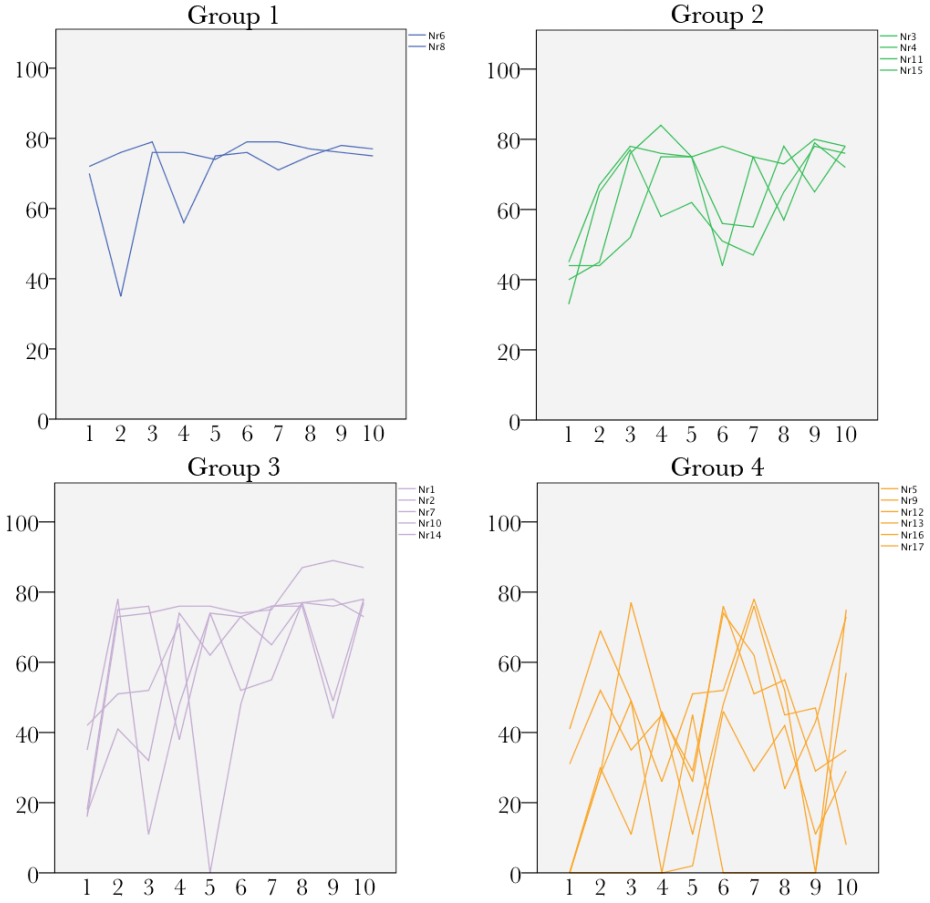


Figure XIII. Learning curves for individuals divided into four groups based on their performance. Group 1 high level of innate abilities, gaining little improvement (blue). Group 2 moderate level of innate abilities, gaining improvement (green). Group 3 moderate level of innate abilities, gaining some improvement (pink). Group 4 low level of innate abilities, improvement not demonstrated (orange).

4.3 Results paper III: The simulator scoring system needs improvement for hydromaneuvers and phaco divide and conquer modules

Based on the results in paper I, further analysis was made to analyze the possibility of using the simulator score for assessment for the cataract specific modules capsulorhexis, hydromaneuvers and phaco divide and conquer. ROC curves for these modules were plotted for simulator based scoring and compared with video-based scoring. The areas under the curves were compared between simulator score and video-based scoring. To our knowledge, this is the first report evaluating a simulator with regard to performance score using ROC curve analysis.

The ROC areas were higher for video scoring for all modules observed, significantly so for phaco divide and conquer ($p=0.01$) (Fig. XIV). In addition, the simulator scoring for the ROC area for hydromaneuvers and phaco divide and conquer, did not differ from hazard judgment and thus were not significantly different from 0.5. Thus, analysis showed that video scores were significantly better as a discriminating tool for cataract surgical skill. Possible explanations for these differences might be that the video-based scaling is smoother. The simulator score has a narrow window of success making a small mistake as vulnerable as a large, often rendering a 0 score thus making discrimination impossible. Furthermore, it seems that video examinations detect skills that are not captured by the inert simulator scoring; video assessment does not only capture surgical mistakes, but also identifies potentially hazardous situations.

This altogether points towards a need for further development of the simulator, perhaps not necessarily on the modules but on the scoring. Today, many institutions have acquired an Eyesi surgical simulator for training[92]. Many also use the simulator for assessment. Our study indicates caution towards using the hydromaneuvers and phaco divide and conquer modules for assessment since the scoring seems to be hazardous. Meanwhile, perhaps the somewhat tedious but accurate assessment would be to analyze the video recordings from the simulator.

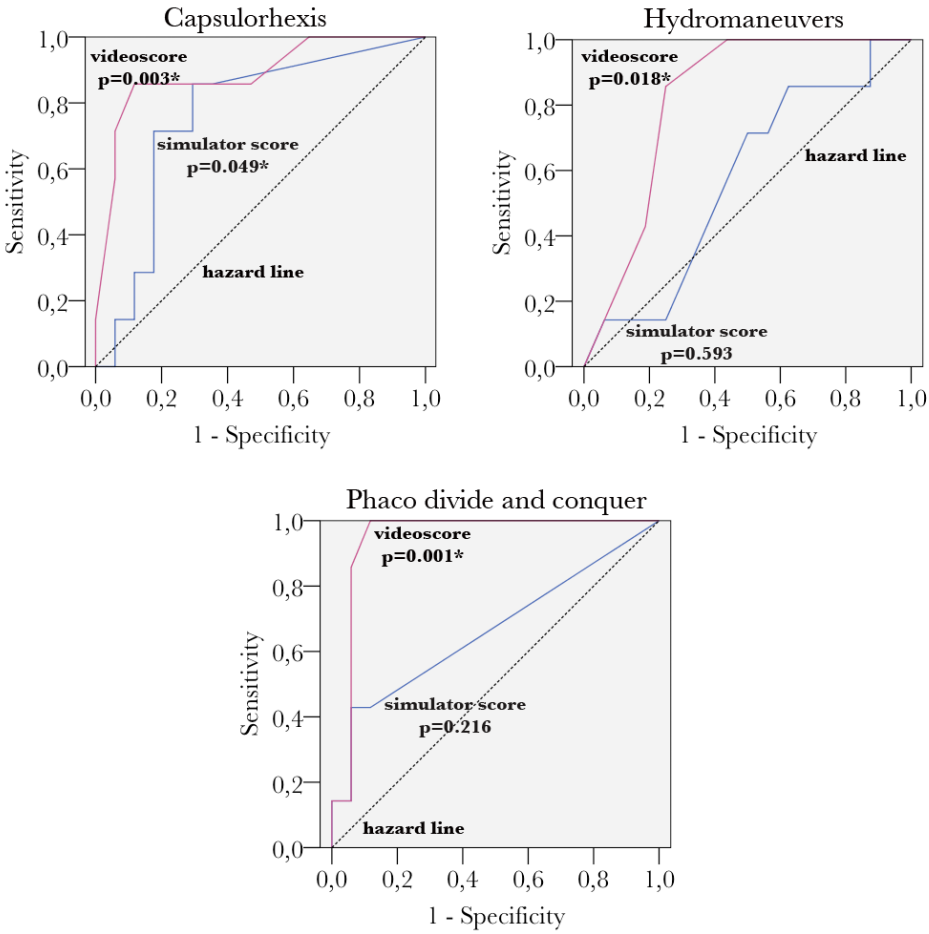


Figure XIV. ROC-curves for simulator score and video-based score respectively for modules capsulorhexis, hydromaneuvers and phaco divide and conquer. Videoscore better than simulator score in phaco divide and conquer module.

4.4 Results and Discussion paper IV: Performance correlates with level of stereoacuity. No sex difference

As indicated in paper II, stereoacuity seemed to affect performance in the surgical simulator. That good stereoacuity could be advantageous in cataract surgery might seem intuitive and in some countries normal stereoacuity is mandatory for ophthalmic surgeons[31]. We let 70 medical students train in the simulator. They performed one iteration on each of the modules cataract navigation training, cataract forceps training and capsulorhexis.

As a previous study had shown a difference between normal and strabismic patients in intraocular surgery training[38], our report is the first to demonstrate a correlation between the level of stereoacuity and performance and this on a group more prone to become cataract surgeons than strabismic patients. In this study, we could demonstrate a correlation between the level of stereoacuity and performance on two manipulating modules on the Eyesi surgical simulator, cataract navigation training ($r=0.377$, $p=0.001$) and cataract forceps training ($r=0.306$, $p=0.01$) but not on capsulorhexis ($r=0.18$, $p=0.136$). Summation of the overall score for each of the three procedures (cataract navigation training, cataract forceps training, capsulorhexis) also correlated to level of stereoacuity ($r=0.386$, $p=0.001$) (Fig. XV).

A detrimental effect on performance was seen such that the worse the stereoacuity, the worse the performance. Even though our results show a correlation between the level of stereoacuity and surgical performance, it did not give enough evidence for excluding individuals with deficient stereoacuity from training as is done in some countries. Firstly, our study did only involve initial training and did not investigate the effect of prolonged training. Whether these differences remain after further training needs further investigation. A study by Suleman et al., showed that a performance gap on a basic laparoscopy task remained also after simulator training for individuals with deficient stereoacuity[37]. Whether this is applicable on ophthalmic surgery is not known, but it is known though that approximately 10% of residents have difficulties in mastering intraocular surgery[22]. Secondly, the performance scores in the group of individuals with deficient stereoacuity varied such that even though most of them had lower scores, there were individuals that performed on the level of those with normal stereoacuity. Apparently these individuals were compensating their lack of stereopsis with other visual and nonvisual cues. A measurement of stereoacuity would perhaps be interesting though, not for exclusion from surgery, but for guidance regarding a plausible need for more or perhaps different training before reaching good levels of performance. This needs to be investigated further.

As noted, correlation between scores and level of stereoacuity was not found for capsulorhexis but was found for cataract navigation training

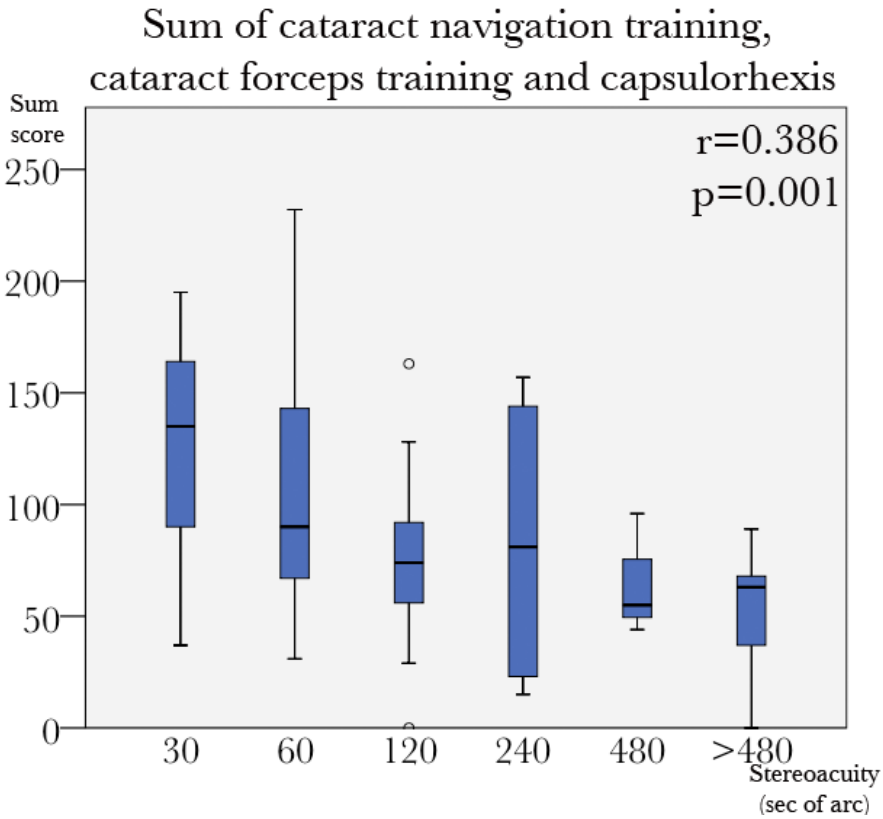


Figure XV. Correlation between level of stereoacuity and sum performance score for modules cataract navigation training, cataract forceps training and capsulorhexis. Median= thick horizontal line, boxes = 25 and 75% percentiles, whiskers = min and max.

and cataract forceps training. Being a more complex procedure, compared to the two manipulating modules, capsulorhexis is dependent on other factors such as understanding of tissue behavior and ability to focus attention not only to the grasping area but also to other areas of interest when moving the forceps. Also, capsulorhexis is performed mostly in one plane and other visual cues might compensate for the lack of stereoacuity. Besides, capsulorhexis was performed on the easiest level of difficulty and perhaps that level was too easy to be able to discriminate differences based on stereoacuity.

In our study, 21 of the 70 (30%) students had a deficient stereoacuity (i.e. > 60 seconds of arc). This is in accordance with the results of Rawlinson where they found that about 24% of dental students had a deficient

stereoacuity[30]. Our results, even though being a little higher, still fall into the statistical variation of a prevalence of 0,24 using a p value of 0.05. Comparing with a population based report where Rahi et al. investigated a 1958 British birth cohort, they found an incidence of deficient stereoacuity of 14%[29]. They tested stereoacuity with Lang II stereo card. This test is known to have low sensitivity in screening so perhaps the real figures are a little bit higher[93,94]. We chose to use the TNO charts in our study because it does not possess any contour stimulus but rather captures the true disparities. Other tests such as the Titmus and Lang also give contour specific stimuli and that might be one of the explanations for giving better stereoacuity scores on screening[27]. For our purposes, perhaps a stereoacuity test such at the Titmus might actually have been more relevant since it also takes into account the disparity of real contours in objects and therefore more mimics factors that are important in a real operative setting. Stereoacuity measured with Titmus might have correlated even more with performance than stereoacuity measured with TNO charts.

Exposure time plays a role in perceiving depth on tests[95]. Our participants were given plenty of time and were free to move to a specially designated light source. Viewing distance was however kept at 40 cm all the time.

An additional explanation to our high threshold levels of stereoacuity among the students might have been the testing conditions. The stereoacuity was measured in the same room in which we also have placed our simulator. This room is situated in a basement with little daylight. The room is well lit and standardized light bulbs have been used in the room. If our testing conditions give higher thresholds than expected, since the TNO score parameter is an analogue measurement, the scale would in this case be shifted a little bit but one would assume that the proportions among the groups would remain unchanged and therefore the correlation with simulator scores would not be affected.

The data in this study was treated as non-Gaussian since the simulator scores were not normally distributed and included truncations. Also the grouping variable threshold level of stereoacuity, however continuous in nature, the threshold grouping of the variable turns it into an ordinal variable making it less suitable for using parametric statistical analysis.

We did not find any difference in performance between men and women among the parameters analyzed. Among previous reports on surgical simulators, a few have shown gender differences but many have shown no

such differences[78-80,96]. Previous video exposure and interest in surgical training have been reported as being confounding factors. Our material included a large study group of participants and therefore it is likely that gender effects are negligible in early anterior segment surgical training.

OVERALL DISCUSSION - SIMULATOR TRAINING CAN REPLACE SOME OF TODAYS TRAINING ON PATIENTS

STUDY RESULTS

Training of intraocular surgeons has come into focus. Our first paper describes construct validity for the cataract surgery simulator Eyesi, i.e. the simulator captures skills attributed to cataract surgeons and through our studies we have distinguished levels of proficiency for several modules. For the cataract specific modules, the discrimination between surgeons and naïve subjects based on simulator score was most pronounced for capsulorhexis. On the hydromaneuvers and phaco divide and conquer modules, the simulator scoring had difficulties in distinguishing the two groups. Further analysis in paper III revealed that the ROC curve areas for computer scoring of hydromaneuvers and phaco divide and conquer did not differ from 0.5. Also, analysis showed that video scores were significantly better as a diagnostic tool for cataract surgical skill. This altogether points towards a need for further development of the simulator, perhaps not necessarily on the modules but on the scoring. Today, many institutions have captured an Eyesi surgical simulator for training[92]. Many use the simulator for training, which based on our results would seem reasonable. Many also use the simulator for assessment. Our findings in paper III indicates caution towards using the hydromaneuvers and phaco divide and conquer modules for assessment since the scoring seems to be hazardous. Meanwhile, perhaps the somewhat tedious but accurate assessment would be to analyze the video recording on the simulator. Videoevaluation is an already validated method for assessment.

Training of cataract surgeons is costly[40] and complications are higher for new surgeons[14]. Today, training of new surgeons is based on scarce wet-lab training[59] but mainly on patients. New surgeons that have never operated before, can after training on pig eyes, under supervision perform parts of operations on humans; there has been no alternatives. We have shown that naïve individuals can train in the simulator and improve their scoring with practice (paper II). For other medical fields, such as colonoscopy[88] and laparoscopic surgery[65], simulator training has shown beneficial effect on early clinical performance. Whether VR training to levels of proficiency does improve real cataract operative performance however is not known. Feudner et al. reported improved performance in wet-lab capsulorhexis for individuals trained in simulator surgery[97]. For real operations, Belyea et al. reported less complications and improved operative performance after

introduction of Eyesi simulator training in their institution[98]. An objection is that this was a retrospective report and several other parameters might have changed thus questioning whether the change was contributed to simulator training only. Despite these objections, most scientific results point towards a beneficial effect of training in surgical simulators, indicating that the learning curve for cataract surgery potentially could be moved out of the operating room with simulator training.

INDIVIDUALIZED TRAINING

As is noticed in our material, skills at baseline vary between individuals and we could see that some individuals with bad stereoacuity (paper II) had difficulties in improving their performance score whereas some individuals reached high levels after just a few iterations. We could also se that the level of stereoacuity correlated with performance on the simulator at initial training (paper IV). This factor may have impact in the recruitment and training of new cataract surgeons. The variations between individuals were however large, such that some individuals despite deficient stereoacuity performed on levels of those with normal stereoacuity. Other studies have shown influence of previous computer experience on performance on VR surgery simulators[99] and some have reported no benefit at all for a group when VR trained[91]. Visuospatial ability is another factor that has shown to affect performance on surgical simulators[100]. Altogether this points towards an individualized training model with predefined target criteria (proficiency levels) instead of the old master-apprentice model that is still widely used for surgical training. Individuals that need more training can be identified and can be given extra possibilities for training. For these purposes, a simulator is well suited for training where difficult parts can be trained separately and intensely, it is possible to repeat exactly and measure improvement, and the deliberate practice approach is easily applicable.

THE STRUCTURE OF TRAINING – COMPETENCE BASED CURRICULUM

How simulation based training should be structured to be efficient have been discussed[101]. It is known that distributed practice works better than massed practice[63,102]. To receive feedback on progress is also important for learning[63,103,104]. Training has to be challenging enough to be efficient[89]. Training has to involve clear goals[63,105] and it its important that training is integrated with a curriculum[101].

Surgical training of new intraocular surgeons internationally is still dependent on the apprenticeship model and there is no reason to believe that the situation is different in Sweden[106]. The cataract registry take notice of complications during cataract surgery for each registered operative unit but no specific database for follow up of surgeons under training exists. As Rogers et al show, the introduction of a structured surgical curriculum has reduced the complications associated with surgery[107]. A national initiative needs to be taken to change the view of surgical training in Sweden[108]. A shift from counting operating cases to measure operative performance and operative outcome has to be done[52]; competence based curriculum has to be designed in which simulator based training together with wet-lab is a part and where surgical progress and outcome is measured and assessed with validated assessment tools such as OSACSS and OSATS.

CONCLUSIONS

- Evidence for construct validity was found for cataract specific modules capsulorhexis, hydromaneuvers and phaco divide and conquer on the Eyesi cataract intraocular surgical simulator. Construct validity was also found for manipulating modules cataract navigation training, cataract forceps training and cataract cracking and chopping training. For the hydromaneuvers and phaco divide and conquer modules, the innate simulator scoring could not distinguish surgical skill but discrimination was dependent on video-based human scoring (OSACSS). Concurrent validity was found for the capsulorhexis module (Paper I).

- Learning curves were investigated for modules capsulorhexis and cataract navigation training. Naïve individuals reached plateau levels of performance on cataract navigation training with ten iterations but not on capsulorhexis even though improvement was evident. Evidence for concurrent validity was reconfirmed for the capsulorhexis module. (Paper II).

- Innate simulator scoring was not different from hazard score for modules hydromaneuvers and phaco divide and conquer. Video-based human scoring was superior to innate simulator scoring on the phaco divide and conquer module (Paper III).

- Stereoacuity was found to correlate with performance on the simulator but there were large individual variations. (Paper IV).

- No differences in performance on the simulator were found between men and women (Paper IV).

- Simulation-based VR cataract surgical training has the potential to move the early training out of the operating room. Future studies need to focus on the correlation between simulation based training and improved operative performance. Future studies should also address the influence of factors such as previous videogame experience and visuospatial abilities on such training.

POPULÄRVETENSKAPLIG SAMMANFATTNING

BAKGRUND VALIDERING OCH ANVÄNDBARHET AV SIMULATOR FÖR TRÄNING AV ÖGONKIRURGI

ÖKAD EFTERFRÅGAN AV ÖGONOPERATIONER

Området ögonkirurgi har genomgått en enorm teknisk utveckling. Från att behandla näthinneavlossning konservativt till högteknologivitrektomi, från stora incisioner för gråstarrskirurgi utan intraokulära linser till millimeterstora snitt med multifokala linser som gör patienter glasögonoberoende. Gråstarrsoperation, en operation där man byter ut ögats lins mot en plastlins, är en av de vanligaste operationerna i Sverige idag. En åldrande befolkning med ökande krav på livskvalitet och bra synskärpa har lett till att allt fler opereras och opereras vid yngre ålder och vid bättre synskärpa. Varje år utförs i Sverige ca 90 000 gråstarrsoperationer.

HÖGRE KRAV PÅ KVALITETSKONTROLL

Sedan början av 90-talet har kvalitetsregister för gråstarrskirurgi följt utvecklingen vad gäller kvalitetsindikatorer och komplikationer till gråstarrskirurgi. Krav från Socialstyrelsen såväl som från allmänheten har satt kvalitet i fokus. Komplikationer under och efter kirurgi är kostsamma och skadliga för patienterna; kapselbrott vid gråstarrskirurgi leder till kraftigt ökad risk för näthinneavlossning och efterföljande dålig syn.

ÖKADE KRAV PÅ SÄKER TRÄNING AV BLIVANDE ÖGONKIRURGER

Att allt fler operationer utförs kräver också utbildning av fler ögonkirurger och uppskattningsvis ett 30-tal kirurger är för närvarande under upplärning för gråstarrskirurgi i Sverige. Inom flyget tränas piloter i simulatorer innan de tillåts flyga nya flygplansmodeller. De utvärderas i flera steg och måste uppvisa duglighet innan de får flyga riktiga plan. Flygplanssimulatorer är en viktig del av denna träning. Någon sådan standard finns inte för blivande ögonkirurger. Utbildning av blivande ögonkirurger är tidsödande och risken för komplikationer som t.ex. kapselbrott är betydligt högre för nya gråstarrskirurger jämfört med erfarna kirurger. Gråstarrskirurger under utbildning har också en mindre effektiv operationsteknik och använder mer ultraljudsenergi vilket är ogynnsamt för hornhinnans endotel (inre lager). Det vore således önskvärt att flytta inlärningskurvan för blivande ögonkirurger ut ur operationssalen. Upplärning av kirurger har traditionellt genomförts via handledare-adeptmodell. Det finns dock en ambition att gå mot ett kompetensbaserat curriculum.

INTRODUKTION TILL STUDIERNA

TRÄNING AV BLIVANDE KIRURGER

Träning av blivande ögonkirurger är tidsödande och kostsam. Att lära sig gråstarrskirurgi kräver väl utvecklade psykomotoriska färdigheter och undersökning visar att ca 10% av blivande kirurger har svårigheter att klara de kirurgiska färdigheterna. Utvecklingen av träningsprogram för ögonkirurger och uppföljning av lärandeprocessen är fortfarande i sin linda och endast ett fåtal är publicerade. Validering är inkomplett. Idag ges möjlighet för träning punktvis i wet-lab men den huvudsakliga träningen av blivande kirurger sker i operationssalen på verkliga patienter.

Capsulorhexis (det moment då kapseln öppnas) och phaco (då man med ultraljudsteknik suger ut den grumliga linskärnan) är de två procedurer som blivande kirurger finner är svårast att lära sig. För att träning skall vara effektiv bör den vara spridd på flera träningstillfällen. Det är också fördelaktigt att kunna träna utvalda delar separat. Simulatorer erbjuder just dessa möjligheter. De är lätta att använda utan omständliga förberedelser. Inlärning kan mätas och följas och vid utebliven förbättring kan extra träning ges.

SIMULATORER FÖR TRÄNING AV ÖGONKIRURGI

Simulatorer för träning av kirurgiska färdigheter har använts inom allmänkirurgi och man har också visat att sådan träning har förbättrat utfall vid verkliga operationer. Simulatorer för träning av ögonkirurgi är i sin linda även om några system har presenterats. Två kommersiella system finns för träning av ögonkirurgi; Eyesi (VRmagic, Tyskland) och PhacoVision (Melerit, Sverige). PhacoVision är en simulator för träning av gråstarrskirurgi. Eyesi är en simulator med möjlighet att träna både gråstarrskirurgi och bakre segmentskirurgi.

Innan en kirurgisimulator inkluderas i träningsprogram bör den utvärderas för hur väl den liknar den verklighet den skall simulera, ”construct validity” eller konstruktvaliditet. Detta är ofta undersökt genom att utvärdera om utfall för olika övningar skiljer mellan individer med olika kirurgisk kompetens. Vidare undersöks om det finns samstämmighet mellan de bedömningar simulatorn levererar och annan känd mätmetod, ”concurrent validity” eller kriterievaliditet.

För Eyesi kirurgisimulator har rapporter visat konstruktvaliditet för capsulorhexis men inga studier har rapporterat validitet för de andra kirurgispecifika modulerna bl.a. hydrodissektion (då linskärnan lossas från

omgivande bark) och phaco. Vidare är inlärningskurvorna för dessa moduler inte undersökta. Inga studier har undersökt kriterievaliditet.

Individer lär sig med olika hastighet och har olika utgångslägen då träning startar. Kön har sagts vara en faktor som påverkar förutsättningarna för kirurgisk träning men andra studier har inte kunnat påvisa sådana skillnader. Man har också sett att nivå av stereoseende och visuospatial förmåga påverkar prestation i simulatorer för kirurgisk träning. Inledande studier har visat att dåligt stereoseende försämrar prestation i ögonkirurgisimulator för strabismpatienter men om det finns en korrelation till graden av stereoseende är inte utrett. Inte heller om fynden är applicerbara på blivande kirurger. Huruvida visuospatial förmåga påverkar prestation vid ögonkirurgi är inte känt.

Ögonsimulatorn Eyesi

Studierna som redovisas i denna avhandling har genomförts med hjälp av Eyesi kirurgisimulator. Simulatorn består av ett modellöga som sitter på ett dockhuvud. Det finns ett huvud med tillhörande öga för träning av gråstarrskirurgi och ett för träning av näthinnekirurgi. Inne i ögat detekterar kameror rörelser av de instrument som förs in i ögat. Rörelserna registreras och bearbetas till en virtuell bild som presenteras i det fiktiva operationsmikroskopets okular. På en sidoskärm ses samma bild som presenteras i okularen. Verklighetstrogna operationsprocedurer för gråstarrskirurgi och näthinnekirurgi tränas i olika moduler. För varje övning räknar simulatorn ut en poängsumma mellan 0 och 100 som ett betyg på hur väl momentet utförts. Dessutom ges ytterligare prestationsbaserade parametrar som bl.a. reflekterar skador på vävnader och tidsåtgång.

Syfte

Målsättning med avhandlingsarbetet har varit att utvärdera Eyesi kirurgisimulator och undersöka hur den kan användas för att träna intraokulärkirurgi. Mer specifikt har avsetts att:

I. undersöka hur väl det går att särskilja kirurgisk förmåga i Eyesi då man jämför kirurger med naiva (”construct validity”)
II. undersöka om icke-kirurger kan träna upp sina prestationer i simulatorn
III. utvärdera hur det poängsystem som finns i Eyesi fungerar om man använder simulatorn som bedömningsverktyg för gråstarrkirurgisk

förmåga

IV. undersöka huruvida andra faktorer såsom kön och stereoseende påverkar prestation i Eyesi kirurgisimulator

RESULTAT: SIMULATORTRÄNING KAN FÖRBÄTTRA KIRURGISK FÖRMÅGA FÖR BLIVANDE ÖGONKIRURGER

KIRURGER PRESTERAR BÄTTRE ÄN ICKE-KIRURGER I EYESI (I)

Gråstarrskirurger och icke-kirurger (naiva) fick genomföra procedurspecifika övningar (capsulorhexis, hydromaneuvers och phaco divide and conquer) och manipuleringsövningar i Eyesi. Poängen på respektive övning jämfördes mellan de två grupperna. Kirurgerna fick bättre poäng jämfört med naiva på de flesta moment. Videoinspelningar av operationerna visade tydliga skillnader mellan kirurger och naiva där kirurgerna fick högre poäng. Kirurgerna var också snabbare. De naiva skadade hornhinnan och linsen mer under kirurgin jämfört med kirurgerna och hade en mindre effektiv operationsteknik.

Genom denna studie kunde konstruktvaliditet visas för modulerna hydromaneuvers och phaco divide and conquer. Konstruktvaliditet kunde konfirmeras för capsulorhexis. Det innebär att Eyesi för de undersökta modulerna liknar en verklig gråstarrsoperation i sådan utsträckning att den särskiljer kirurger från icke-kirurger. Noterbart är dock att det var genom videobedömningarna denna skillnad blev tydlig, inte genom den poängsättning som levereras via simulatorns programvara. För att uppmäta skillnader krävs således videoinspelning av träningsmomenten vilket är både tidsödande och opraktiskt. Ett bättre poängbedömningssystem vore därför önskvärt.

DET GÅR ATT TRÄNA UPP DEN KIRURGISKA FÖRMÅGAN I EYESI (II)

35 medicine studerande slumpades till att träna tio ggr i antingen capsulorhexis eller en manipuleringsövning (”cataract navigation training”) varefter de tränade två gånger i den andra modulen. Inlärningskurvorna analyserades. Det visade sig att studenterna fick bättre poäng och nådde en platå för poäng vid träning i cataract navigation training men inte vid träning i capsulorhexis. I båda modulerna blev deltagarna dock snabbare. De blev också försiktigare med instrumenten och skadade både hornhinna och lins mindre med träning. Vid byte från en modul till den andra sågs ingen påverkan av träning i den andra modulen talande för att modulerna tränar olika kirurgiska förmågor.

Vi har här visat att det genom att träna i Eyesi går att förbättra resultaten både vad gäller poäng och övriga parametrar. Vävnadsskador ses ofta i tidig kirurgisk träning och man har också visat att simulatorträning inom andra kirurgiska discipliner kan minska dessa skador. I vår studie kunde vi se att med träning minskade skadorna på hornhinna och lins. Simulatorn har därför en möjlighet att vara del av den initiala träningen av blivande gråstarrskirurger.

VIDEOBEDÖMNINGAR SÄKRARE ÄN SIMULATORNS POÄNGSYSTEM (III)

Eyesi är den dominerande simulatorn för träning av intraokulärkirurgi. Simulatorn används för träning av kirurgi men också för utvärdering. Poängsättningen är dock inte validerad. Baserat på träning från kirurger och icke-kirurger jämfördes poängsättning i Eyesi med videobedömningar av capsulorhexis, hydromaneuvers och phaco divide and conquer. Filmerna, som var avidentifierade, bedömdes av två gråstarrskirurger med validerade filmbedömningsverktyg. ROC-kurvor analyserades och jämfördes. Det visade sig att för hydromaneuvers och phaco divide and conquer var den inbyggda poängsättningen i simulatorn inte bättre på att urskilja kirurgerna än slumpen. Då man gjorde videobedömningar av procedurerna och använde poäng från videobedömningarna var det lätt att urskilja kirurgerna. För phacomodulen var videobedömningarna klart bättre än den inbyggda simulatorpoängsättningen.

Att använda simulatorn inbyggda poäng för utvärdering av capsulorhexis går bra. För hydromaneuvers och phaco divide and conquer är simulatorpoängen inte bättre än slumpen. Videobaserad poängsättning fungerar bra och är klart bättre än den inbyggda simulatorpoängen och detta talar också för att poängsättningen i simulatorn behöver utvecklas.

PRESTATIONEN KORRELERAR MED STEREOSEENDET – JU SÄMRE STEREOSEENDE DESTO SÄMRE PRESTATION. INGEN SKILLNAD MELLAN MÄN OCH KVINNOR (IV)

70 medicine studerande deltog i studien och fick utföra två manipuleringsövningar och en gråstarrspecifik övning, capsulorhexis. Stereoseendet på deltagarna mättes. Vi fann en korrelation mellan graden av stereoseende och erhållna poäng i simulatorn för manipuleringsmodulerna men inte för capsulorhexis även om samma trend sågs även för denna modul. Gråstarr opereras med mikroskop. Att stereoseendet kan vara en viktig faktor vilket vi visar, kan man intuitivt misstänka. Att detta inte blev tydligt för capsulorhexis kan dels bero på att det är en komplex procedur och stereoseendet är endast en faktor som bidrar till hur väl den utförs.

Personer med defekt stereoseende kan lära sig att kompensera för sin brist på stereoseende. I capsulorhexisproceduren rör man sig också mest i ett plan, djupseendet kanske inte blir så betydelsefullt i just detta moment.

Vår studie har undersökt koppling mellan stereoseende och inledande träning. Detta är endast en första träning. Vi vet inget om hur defekt stereoseende påverkar träning i ett längre perspektiv. Vi kunde också konstatera att det fanns individer med dåligt stereoseende som trots detta presterade i nivå med dem med normalt stereoseende. I vissa länder exkluderar man individer med defekt stereoseende från att bli ögonkirurger. Vi ser inte att det idag finns vetenskapliga bevis för detta, ej heller med vår studie. Inom andra kirurgiska discipliner har man sett att det tar längre tid att träna upp sin kirurgiska förmåga för individer med defekt stereoseende. Huruvida detta är applicerbart på ögonkirurgi är inte känt.

Vi undersökte också eventuella skillnader i prestation mellan män och kvinnor. Inga skillnader sågs.

BETYDELSE: TRÄNING I SIMULATOR KAN ERSÄTTA DAGENS TRÄNING PÅ VERKLIGA PATIENTER

Vi har visat att Eyesi ögonkirurgisimulator kan urskilja ögonkirurger från icke-kirurger. Vi har också visat att blivande kirurger kan träna i simulatorn och förbättra sina resultat med träning. Vidare har vi sett att en faktor så som stereoseende, men inte kön, spelar en roll för hur bra man presterar i simulatorn som icke-kirurg.

Träning av blivande ögonkirurger är kostsam och komplikationerna är högre för nya kirurger. Idag sker utbildning av kirurger i viss mån på grisögon men framförallt på patienter. Nya ögonkirurger som aldrig opererat tidigare får efter träning på grisögon och under handledning utföra delar av operationer på människor eftersom det inte har funnits några alternativ. Med effektiv träning i simulatorn finns förhoppning att detta också leder till förbättrade resultat vid verkliga operationer och att en del av inlärningskurvan därmed kan flyttas ut ur operationssalen.

Det har rapporterats att ca 10% av blivande ögonkirurger har bekymmer med att lära sig de kirurgiska färdigheterna. I våra studier har vi sett att olika individer presterar på olika nivåer, några presterar bättre resultat och andra sämre. Vi har bl.a. sett en korrelation mellan prestation och stereoseende.

Tillsammans talar detta för en individualiserad träningsmodell med fördefinierade målkriterier istället för den gamla lärlingsmodell som fortfarande mycket används för att lära ut kirurgi. Individer som behöver mer träning kan identifieras och kan få ytterligare möjligheter för träning. Man kan också upprepa exakt och mäta förbättring. I detta passar simulatorn väl in där svåra delmoment kan tränas extra intensivt.

Hur simulatorbaserad träning skall struktureras för att bli effektiv har diskuterats. Det är känt att spridd träning fungerar bättre än massträning. Att få återkoppling på sin utveckling är också viktigt för lärandet. Träningen måste vara tillräckligt utmanande för att vara effektiv. Träningen måste ha tydliga mål och det är viktigt att träningen integreras med curriculum.

Kirurgisk träning för blivande ögonkirurger internationellt förlitar sig fortfarande mycket på lärlingsmodellen och det finns ingen anledning att tro att situationen är annorlunda i Sverige. Gråstarrsregistret registrerar komplikationer vid gråstarrskirurgi för varje enhet men ingen särskild databas för uppföljning av resultat för kirurger under träning finns. Man har i en studie visat att införandet av ett strukturerat curriculum för träning, minskat komplikationer vid gråstarrskirurgi. Ett nationellt initiativ kan komma att behöva tas för att förändra synen på kirurgisk träning i Sverige. Ett skifte från att räkna antal operationer till att mäta operationsutfall och kirurgisk förmåga måste ske; kompetensbaserade curriculum måste utformas i vilken simulatorträning tillsammans med wet-lab ingår och där kirurgisk utveckling mäts med validerade bedömningsverktyg.

ACKNOWLEDGEMENTS

Work was performed at Lund University. I would like to express my gratitude to all who helped and supported me during the work with this thesis. In particular I would like to thank:

Doc **Peter Åsman**, my supervisor. Your enthusiasm and harmonic personality has made working together fun. I also appreciate your intelligence and the fruitful scientific discussions we have had. Your ability to handle language, Swedish and English, is brilliant; I'm trying to learn from you.

Prof **Anders Bergenfeltz**, my co-supervisor for good advice along the road.

Prof. **Anders Heijl** for providing the scientific base for research at our clinic. Also, for interesting discussions in the beginning of my research project.

Prof **Elisabet Agardh** for your good suggestions for handling the important non-scientific aspects of being a PhD student in a smart way.

Britt Beding-Barnekow for having the ability to match me with such a perfect research subject. Your visions regarding research with the surgical simulator was the starting point for my research. Also, I am very grateful for you giving me the opportunity to join the vitreoretinal team in Malmö when I first started vitreoretinal surgery.

Jerker Börrén for your good technical knowledge and support, always finding solutions for problems that occurred with the simulator.

Johnny Ring for help with computer-related problems and poster preparation.

Anette Lindström for always being very helpful in arranging practicalities regarding schedules trying to fit clinical work with research and family life.

Colleagues for providing a good working atmosphere. In particular my colleagues on the vitreoretinal surgery team, past and present, at the Department of Ophthalmology at Skåne university hospital. Especially I would like to mention **Joakim Thylefors** for being such a loyal and good colleague.

Friends for showing me that life does not only circle around ophthalmology.

My family, my mother **Ingrid** who has always supported and encouraged me when I want to set out for new goals. My father **Harald,** always enthusiastic about ophthalmology. Your patient stories during dinner table made ophthalmology sound adventurous. My sister **Gabriella**, for being the best friend and support especially when life takes unwanted turns. My wonderful children, **Louise** and **Ebba**, for giving me the ultimate joy in life.

The studies were supported financially by grants from the Herman Järhardt Foundation, Malmö, Sweden, the Medical Faculty, Lund University, Sweden, and the Foundation for Visually Impaired in Former Malmöhus län, Sweden.

The author has no commercial or proprietary interest in the instrument described.

REFERENCES

1. Minihan M, Tanner V, Williamson TH. Primary rhegmatogenous retinal detachment: 20 years of change. *Br J Ophthalmol* 2001;85:546-8.

2. Krwawicz T. Further Experience with Intracapsular Cataract Extraction by Application of Low Temperature. *Br J Ophthalmol* 1963;47:36-8.

3. Lundstrom M, Stenevi U, Thorburn W. The Swedish National Cataract Register: A 9-year review. *Acta Ophthalmol Scand* 2002;80:248-57.

4. Zaidi FH, Corbett MC, Burton BJ, Bloom PA. Raising the benchmark for the 21st century--the 1000 cataract operations audit and survey: outcomes, consultant-supervised training and sourcing NHS choice. *Br J Ophthalmol* 2007;91:731-6.

5. de Vries NE, Nuijts RM. Multifocal intraocular lenses in cataract surgery: literature review of benefits and side effects. *Journal of cataract and refractive surgery* 2013;39:268-78.

6. Statistiska centralbyrån. Åldrande befolkning. http://wwwscbse/Pages/Vislet____331316.aspx. Accessed March 30, 2013.

7. Nationella Kataraktregistret. Årsrapport 2011. http://cataractregcom/Cataract_Sve/2Final%C3%A5rsrapp_2011pdf. Accessed March 30, 2013.

8. Behndig A, Montan P, Stenevi U, Kugelberg M, Lundstrom M. One million cataract surgeries: Swedish National Cataract Register 1992-2009. *Journal of cataract and refractive surgery* 2011;37:1539-45.

9. Sveriges Kommuner och Landsting. Nationella Kvalitetsregister inom hälso- och sjukvården 2010.

10. Socialdepartementet, Regeringskansliet. Översyn av de nationella kvalitetsregistren guldgruvan i hälso- och sjukvården. Förslag till gemensam satsning 2011–2015.

11. Jakobsson G, Montan P, Zetterberg M, Stenevi U, Behndig A, Lundstrom M. Capsule complication during cataract surgery: Retinal detachment after cataract surgery with capsule complication: Swedish Capsule Rupture Study Group report 4. *Journal of cataract and refractive surgery* 2009;35:1699-705.

12. McGreevy JM. The aviation paradigm and surgical education. *J Am Coll Surg* 2005;201:110-7.

13. O'Day DM. Assessing surgical competence in ophthalmology training programs. *Archives of ophthalmology* 2007;125:395-6.

14. Randleman JB, Wolfe JD, Woodward M, Lynn MJ, Cherwek DH, Srivastava SK. The resident surgeon phacoemulsification learning curve. *Archives of ophthalmology* 2007;125:1215-9.

15. Shaw AD, Ang GS, Eke T. Phacoemulsification complication rates. *Ophthalmology* 2007;114:2101-2.

16. Mahdy MA, Eid MZ, Mohammed MA, Hafez A, Bhatia J. Relationship between endothelial cell loss and microcoaxial phacoemulsification parameters in noncomplicated cataract surgery. *Clin Ophthalmol* 2012;6:503-10.

17. Scott DJ, Dunnington GL. The new ACS/APDS Skills Curriculum: moving the learning curve out of the operating room. *J Gastrointest Surg* 2008;12:213-21.

18. Ahlberg G, Kruuna O, Leijonmarck CE, et al. Is the learning curve for laparoscopic fundoplication determined by the teacher or the pupil? *American journal of surgery* 2005;189:184-9.

19. Grodin MH, Johnson TM, Acree JL, Glaser BM. Ophthalmic surgical training: a curriculum to enhance surgical simulation. *Retina* 2008;28:1509-14.

20. Accreditatoin Council for Graduate Medical Education, ACGME. http://wwwacgmeorg/acgmeweb/. Accessed March 28, 2013.

21. Leach DC. The ACGME competencies: substance or form? Accreditation Council for Graduate Medical Education. *J Am Coll Surg* 2001;192:396-8.

22. Binenbaum G, Volpe NJ. Ophthalmology resident surgical competency: a national survey. *Ophthalmology* 2006;113:1237-44.

23. Fielder AR, Moseley MJ. Does stereopsis matter in humans? *Eye* 1996;10 (Pt 2):233-8.

24. Julesz B. Binocular Depth Perception without Familiarity Cues. *Science* 1964;145:356-62.

25. Wright LA, Wormald RP. Stereopsis and ageing. *Eye* 1992;6 (Pt 5):473-6.

26. Grober ED, Hamstra SJ, Wanzel KR, et al. Validation of novel and objective measures of microsurgical skill: Hand-motion analysis and stereoscopic visual acuity. *Microsurgery* 2003;23:317-22.

27. Garnham L, Sloper JJ. Effect of age on adult stereoacuity as measured by different types of stereotest. *Br J Ophthalmol* 2006;90:91-5.

28. Nongpiur ME, Sharma P. Horizontal Lang two-pencil test as a screening test for stereopsis and binocularity. *Indian J Ophthalmol* 2010;58:287-90.

29. Rahi JS, Cumberland PM, Peckham CS. Visual impairment and vision-related quality of life in working-age adults: findings in the 1958 British birth cohort. *Ophthalmology* 2009;116:270-4.

30. Rawlinson A. A simple eyesight screening programme for dental undergraduates: results after 7 years. *Aust Dent J* 1993;38:394-9.

31. Wong NW, Stokes J, Foss AJ, McGraw PV. Should there be a visual standard for ophthalmologists and other surgeons? *Postgrad Med J* 2010;86:354-8.

32. Webber AL, Wood JM, Gole GA, Brown B. The effect of amblyopia on fine motor skills in children. *Invest Ophthalmol Vis Sci* 2008;49:594-603.

33. Murdoch JR, McGhee CN, Glover V. The relationship between stereopsis and fine manual dexterity: pilot study of a new instrument. *Eye* 1991;5 (Pt 5):642-3.

34. Melmoth DR, Finlay AL, Morgan MJ, Grant S. Grasping deficits and adaptations in adults with stereo vision losses. *Invest Ophthalmol Vis Sci* 2009;50:3711-20.

35. Mazyn LI, Lenoir M, Montagne G, Savelsbergh GJ. The contribution of stereo vision to one-handed catching. *Exp Brain Res* 2004;157:383-90.

36. Barry GP, Simon JW, Auringer D, Dunnican W, Zobal-Ratner J. Performance of strabismic subjects using a validated surgical training module: a pilot study. *J Aapos* 2009;13:350-3, 3 e1-2.

37. Suleman R, Yang T, Paige J, et al. Hand-eye dominance and depth perception effects in performance on a basic laparoscopic skills set. *Jsls* 2010;14:35-40.

38. Sachdeva R, Traboulsi EI. Performance of patients with deficient stereoacuity on the EYESi microsurgical simulator. *Am J Ophthalmol* 2011;151:427-33 e1.

39. Rossi JV, Verma D, Fujii GY, et al. Virtual vitreoretinal surgical simulator as a training tool. *Retina* 2004;24:231-6.

40. Hosler MR, Scott IU, Kunselman AR, Wolford KR, Oltra EZ, Murray WB. Impact of resident participation in cataract surgery on operative time and cost. *Ophthalmology* 2012;119:95-8.

41. Oetting TA, Lee AG, Beaver HA, et al. Teaching and assessing surgical competency in ophthalmology training programs. *Ophthalmic Surg Lasers Imaging* 2006;37:384-93.

42. Henderson BA, Grimes KJ, Fintelmann RE, Oetting TA. Stepwise approach to establishing an ophthalmology wet laboratory. *Journal of cataract and refractive surgery* 2009;35:1121-8.

43. Henderson BA, Neaman A, Kim BH, Loewenstein J. Virtual training tool. *Ophthalmology* 2006;113:1058-9.

44. The Royal College of Ophthalmologists. Curriculum for Ophthalmic Specialist Training. http://curriculumrcophthacuk/. Accessed October 15, 2012.

45. Cremers SL, Ciolino JB, Ferrufino-Ponce ZK, Henderson BA. Objective Assessment of Skills in Intraocular Surgery (OASIS). *Ophthalmology* 2005;112:1236-41.

46. Cremers SL, Lora AN, Ferrufino-Ponce ZK. Global Rating Assessment of Skills in Intraocular Surgery (GRASIS). *Ophthalmology* 2005;112:1655-60.

47. Feldman BH, Geist CE. Assessing residents in phacoemulsification. *Ophthalmology* 2007;114:1586.

48. Fisher JB, Binenbaum G, Tapino P, Volpe NJ. Development and face and content validity of an eye surgical skills assessment test for ophthalmology residents. *Ophthalmology* 2006;113:2364-70.

49. Rootman DB, Lam K, Sit M, Liu E, Dubrowski A, Lam WC. Psychometric properties of a new tool to assess task-specific and global competency in cataract surgery. *Ophthalmic Surg Lasers Imaging* 2012;43:229-34.

50. Saleh GM, Gauba V, Mitra A, Litwin AS, Chung AK, Benjamin L. Objective structured assessment of cataract surgical skill. *Archives of ophthalmology* 2007;125:363-6.

51. Gauba V, Saleh GM, Goel S. Ophthalmic plastic surgical skills assessment tool. *Ophthal Plast Reconstr Surg* 2008;24:43-6.

52. Gensheimer WG, Soh JM, Khalifa YM. Objective resident cataract surgery assessments. *Ophthalmology* 2013;120:432-3 e1.

53. Smith RJ, McCannel CA, Gordon LK, et al. Evaluating teaching methods of cataract surgery: validation of an evaluation tool for assessing surgical technique of capsulorhexis. *Journal of cataract and refractive surgery* 2012;38:799-806.

54. Ament CS, Henderson BA. Optimizing resident education in cataract surgery. *Current opinion in ophthalmology* 2011;22:64-7.

55. Lee AG, Greenlee E, Oetting TA, et al. The Iowa ophthalmology wet laboratory curriculum for teaching and assessing cataract surgical competency. *Ophthalmology* 2007;114:e21-6.

56. Hashimoto C, Kurosaka D, Uetsuki Y. Teaching continuous curvilinear capsulorhexis using a postmortem pig eye with simulated cataract(2)(2). *Journal of cataract and refractive surgery* 2001;27:814-6.

57. Borirak-chanyavat S, Lindquist TD, Kaplan HJ. A cadaveric eye model for practicing anterior and posterior segment surgeries. *Ophthalmology* 1995;102:1932-5.

58. Otto CS. Device for simulating anterior segment surgery. *Journal of cataract and refractive surgery* 2005;31:1287-9.

59. Henderson BA, Ali R, Kim JY. Resident surgical competency. *Ophthalmology* 2007;114:829-30; author reply 30.

60. Henderson BA, Ali R. Teaching and assessing competence in cataract surgery. *Current opinion in ophthalmology* 2007;18:27-31.

61. Dooley IJ, O'Brien PD. Subjective difficulty of each stage of phacoemulsification cataract surgery performed by basic surgical trainees. *Journal of cataract and refractive surgery* 2006;32:604-8.

62. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Acad Med* 2004;79:S70-81.

63. Hattie J. Visible learning: a synthesis of over 800 meta-analyses relating to achievement. London: New York: Routledge; 2008.

64. Mackay S, Morgan P, Datta V, Chang A, Darzi A. Practice distribution in procedural skills training: a randomized controlled trial. *Surgical endoscopy* 2002;16:957-61.

65. Seymour NE, Gallagher AG, Roman SA, et al. Virtual reality training improves operating room performance: results of a randomized, double-blinded study. *Ann Surg* 2002;236:458-63; discussion 63-4.

66. Ahlberg G, Enochsson L, Gallagher AG, et al. Proficiency-based virtual reality training significantly reduces the error rate for residents during their first 10 laparoscopic cholecystectomies. *American journal of surgery* 2007;193:797-804.

67. Kundhal PS, Grantcharov TP. Psychomotor performance measured in a virtual environment correlates with technical skills in the operating room. *Surgical endoscopy* 2009;23:645-9.

68. Spiteri A, Aggarwal R, Kersey T, Benjamin L, Darzi A, Bloom P. Phacoemulsification skills training and assessment. *Br J Ophthalmol* 2010;94:536-41.

69. Laurell CG, Soderberg P, Nordh L, Skarman E, Nordqvist P. Computer-simulated phacoemulsification. *Ophthalmology* 2004;111:693-8.

70. Choi KS, Soo S, Chung FL. A virtual training simulator for learning cataract surgery with phacoemulsification. *Computers in biology and medicine* 2009;39:1020-31.

71. Yeh S, Chan-Kai BT, Lauer AK. Basic training module for vitreoretinal surgery and the Casey Eye Institute Vitrectomy

Indices Tool for Skills Assessment. *Clin Ophthalmol* 2011;5:1249-56.

72. Hikichi T, Yoshida A, Igarashi S, et al. Vitreous surgery simulator. *Archives of ophthalmology* 2000;118:1679-81.

73. Söderberg. Virtual Reality Phacoemulsification- a Comparison Between Skilled Surgeons and Students Naive To Cataract Surgery. *SPIE* 2005;5688:164-9.

74. Mahr MA, Hodge DO. Construct validity of anterior segment anti-tremor and forceps surgical simulator training modules: attending versus resident surgeon performance. *Journal of cataract and refractive surgery* 2008;34:980-5.

75. Solverson DJ, Mazzoli RA, Raymond WR, et al. Virtual reality simulation in acquiring and differentiating basic ophthalmic microsurgical skills. *Simul Healthc* 2009;4:98-103.

76. Privett B, Greenlee E, Rogers G, Oetting TA. Construct validity of a surgical simulator as a valid model for capsulorhexis training. *Journal of cataract and refractive surgery* 2010;36:1835-8.

77. Le TD, Adatia FA, Lam WC. Virtual reality ophthalmic surgical simulation as a feasible training and assessment tool: results of a multicentre study. Canadian journal of ophthalmology *Journal canadien d'ophtalmologie* 2011;46:56-60.

78. Shane MD, Pettitt BJ, Morgenthal CB, Smith CD. Should surgical novices trade their retractors for joysticks? Videogame experience decreases the time needed to acquire surgical skills. *Surgical endoscopy* 2008;22:1294-7.

79. Enochsson L, Isaksson B, Tour R, et al. Visuospatial skills and computer game experience influence the performance of virtual endoscopy. *J Gastrointest Surg* 2004;8:876-82; discussion 82.

80. Kolozsvari NO, Andalib A, Kaneva P, et al. Sex is not everything: the role of gender in early performance of a fundamental laparoscopic skill. *Surgical endoscopy* 2011;25:1037-42.

81. Wanzel KR, Hamstra SJ, Caminiti MF, Anastakis DJ, Grober ED, Reznick RK. Visual-spatial ability correlates with efficiency of hand motion and successful surgical performance. *Surgery* 2003;134:750-7.

82. Ahlborg L, Hedman L, Murkes D, et al. Visuospatial ability correlates with performance in simulated gynecological laparoscopy. *Eur J Obstet Gynecol Reprod Biol* 2011;157:73-7.

83. Westman B, Ritter EM, Kjellin A, et al. Visuospatial abilities correlate with performance of senior endoscopy specialist in simulated colonoscopy. *J Gastrointest Surg* 2006;10:593-9.

84. Grantcharov TP, Kristiansen VB, Bendix J, Bardram L, Rosenberg J, Funch-Jensen P. Randomized clinical trial of virtual reality simulation for laparoscopic skills training. *The British journal of surgery* 2004;91:146-50.

85. Schijven MP, Reznick RK, ten Cate OT, et al. Transatlantic comparison of the competence of surgeons at the start of their professional career. *The British journal of surgery* 2010;97:443-9.

86. Ezra DG, Aggarwal R, Michaelides M, et al. Skills acquisition and assessment after a microsurgical skills course for ophthalmology residents. *Ophthalmology* 2009;116:257-62.

87. DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. *Biometrics* 1988;44:837-45.

88. Park J, MacRae H, Musselman LJ, et al. Randomized controlled trial of virtual reality simulator training: transfer to live patients. *American journal of surgery* 2007;194:205-11.

89. Ali MR, Mowery Y, Kaplan B, DeMaria EJ. Training the novice in laparoscopy. More challenge is better. *Surgical endoscopy* 2002;16:1732-6.

90. Feldman LS, Cao J, Andalib A, Fraser S, Fried GM. A method to characterize the learning curve for performance of a fundamental laparoscopic simulator task: defining "learning plateau" and "learning rate". *Surgery* 2009;146:381-6.

91. Schijven MP, Jakimowicz J. The learning curve on the Xitact LS 500 laparoscopy simulator: profiles of performance. *Surgical endoscopy* 2004;18:121-7.

92. Ahmed Y, Scott IU, Greenberg PB. A survey of the role of virtual surgery simulators in ophthalmic graduate medical education. *Graefes Arch Clin Exp Ophthalmol* 2011;249:1263-5.

93. Rasmussen F, Thoren K, Caines E, Andersson J, Tynelius P. Suitability of the lang II random dot stereotest for detecting manifest strabismus in 3-year-old children at child health centres in Sweden. *Acta Paediatr* 2000;89:824-9.

94. Huynh SC, Ojaimi E, Robaei D, Rose K, Mitchell P. Accuracy of the Lang II stereotest in screening for binocular disorders in 6-year-old children. *Am J Ophthalmol* 2005;140:1130-2.

95. Adler FH, Hart WM. Adler's physiology of the eye : clinical application. 9th ed. St. Louis: Mosby Year Book; 1992.

96. Madan AK, Harper JL, Frantzides CT, Tichansky DS. Nonsurgical skills do not predict baseline scores in inanimate box or virtual-reality trainers. *Surgical endoscopy* 2008;22:1686-9.

97. Feudner EM, Engel C, Neuhann IM, Petermeier K, Bartz-Schmidt KU, Szurman P. Virtual reality training improves wet-lab performance of capsulorhexis: results of a randomized, controlled study. *Graefes Arch Clin Exp Ophthalmol* 2009;247:955-63.

98. Belyea DA, Brown SE, Rajjoub LZ. Influence of surgery simulator training on ophthalmology resident phacoemulsification performance. *Journal of cataract and refractive surgery* 2011;37:1756-61.

99. Lynch J, Aughwane P, Hammond TM. Video games and surgical ability: a literature review. *J Surg Educ* 2010;67:184-9.

100. Maan ZN, Maan IN, Darzi AW, Aggarwal R. Systematic review of predictors of surgical performance. *The British journal of surgery* 2012;99:1610-21.

101. McGaghie WC, Issenberg SB, Petrusa ER, Scalese RJ. A critical review of simulation-based medical education research: 2003-2009. *Med Educ* 2010;44:50-63.

102. Verdaasdonk EG, Stassen LP, van Wijk RP, Dankelman J. The influence of different training schedules on the learning of psychomotor skills for endoscopic surgery. *Surgical endoscopy* 2007;21:214-9.

103. Wulf G, Shea C, Lewthwaite R. Motor skill learning and performance: a review of influential factors. *Med Educ* 2010;44:75-84.

104. Mahmood T, Darzi A. The learning curve for a colonoscopy simulator in the absence of any feedback: no feedback, no learning. *Surgical endoscopy* 2004;18:1224-30.

105. Gauger PG, Hauge LS, Andreatta PB, et al. Laparoscopic simulation training with proficiency targets improves practice and performance of novice surgeons. *American journal of surgery* 2010;199:72-80.

106. Golnik KC, Lee AG, Wilson MC. A national program director survey of the shift to competency-based education in ophthalmology. *Ophthalmology* 2008;115:1426-30, 30 e1-2.

107. Rogers GM, Oetting TA, Lee AG, et al. Impact of a structured surgical curriculum on ophthalmic resident cataract surgery complication rates. *Journal of cataract and refractive surgery* 2009;35:1956-60.

108. Ormonde SE. Ophthalmic microsurgical training: are we approaching a crisis point? *Clin Experiment Ophthalmol* 2005;33:453-4.

Paper I

Acta Ophthalmologica

Cataract surgeons outperform medical students in Eyesi virtual reality cataract surgery: evidence for construct validity

Madeleine Selvander[1,2] and Peter Åsman[1]

[1]Department of Clinical Sciences, Malmö: Ophthalmology, Lund University, Malmö, Sweden
[2]Practicum, Skåne University Hospital, Malmö, Sweden

ABSTRACT.
Purpose: **To investigate construct validity for modules hydromaneuvers and phaco on the Eyesi surgical simulator.**
Methods: **Seven cataract surgeons and 17 medical students performed capsulorhexis, hydromaneuvers, phaco, navigation, forceps, cracking and chopping modules in a standardized manner. Three trials were performed on each module (two on phaco) in the above order. Performance parameters as calculated by the simulator for each trial were saved. Video recordings of the second trial of the modules capsulorhexis, hydromaneuvers and phaco were evaluated with the modified Objective Structured Assessment of Surgical Skill (OSATS) and Objective Structured Assessment of Cataract Surgical Skill (OSACSS) tools.**
Results: **Cataract surgeons outperformed medical students with regard to overall score on capsulorhexis ($p < 0.001$, $p = 0.035$, $p = 0.010$ for the tree iterations, respectively), navigation ($p = 0.024$, $p = 0.307$, $p = 0.007$), forceps ($p = 0.017$, $p = 0.03$, $p = 0.028$). Less obvious differences in overall score were found for modules cracking and chopping ($p = 0.266$, $p = 0.022$, $p = 0.324$) and phaco ($p = 0.011$, $p = 0.081$ for the two iterations, respectively). No differences in overall score were found on hydromaneuvers ($p = 0.588$, $p = 0.503$, $p = 0.773$), but surgeons received better scores from the evaluations of the modified OSATS ($p = 0.001$) and OSACSS (capsulorhexis, $p = 0.003$; hydromaneuvers, $p = 0.017$; phaco, $p = 0.001$).**
Conclusions: **Construct validity was found on several modules previously not investigated (phaco, hydromaneuvers, cracking and chopping, navigation), and our results confirm previously demonstrated construct validity for capsulorhexis and forceps modules. Interestingly, validation of the hydromaneuvers module required OSACSS video evaluation tool. A further development of the scoring system in the simulator for the hydromaneuvers module would be advantageous and make training and evaluation of progress more accessible and immediate.**

Key words: cataract surgery – construct validity – simulator – virtual reality

Acta Ophthalmol.
© 2012 The Authors
Acta Ophthalmologica © 2012 Acta Ophthalmologica Scandinavica Foundation

doi: 10.1111/j.1755-3768.2012.02440.x

Introduction

Learning cataract surgery is a timely assignment. Besides requiring resource intense training, inexperienced cataract surgeons also have more complications than more experienced ones (Randleman et al. 2007). Capsulorhexis and phacoemulsification are considered to be the most difficult steps for a new cataract surgeon to handle (Dooley & O'Brien 2006). It would be preferable if the initial learning of these steps could take place in a safe and standardized simulated environment instead of in the operation theatre where standardization is difficult if not impossible, and patient safety is compromised. For some time, surgical simulators have been used to train and assess surgical skills (Thijssen & Schijven 2010). For cataract surgery, a few simulators have been presented (Laurell et al. 2004; Mahr & Hodge 2008; Choi et al. 2009), and the Eyesi surgical simulator (VR Magic AG, Mannheim, Germany) has been partly evaluated for validity (Mahr & Hodge 2008; Privett et al. 2010; Selvander & Asman 2010; Le et al. 2011).

In a retrospective study, Belyea et al. (2011) recently found better phacoemulsification usage in real operations associated with training in a virtual reality eye surgery simulator. It has been shown that, for the capsulorhexis procedure, experienced cataract surgeons perform better than

residents on the Eyesi surgical simulator (Privett et al. 2010). So far though, no studies have reported the validity and training effects specifically for the hydromaneuvers and phaco divide and conquer modules. The aim of this study was to investigate the construct validity for these modules.

Material and Methods

Seven cataract surgeons and seventeen medical students participated in the study. The group of surgeons were recruited on a voluntarily basis and they were practicing at the Skåne University Hospital or at a local hospital in the region. Five of them had performed 800–10 000 cataract operations, one had performed over 150 cataract operations, and one had done 18 cataract operations. The group of students were attending their 9th semester and were recruited during their 6-week ophthalmology rotation.

The students were given a brief orientation on important anterior chamber structures before the simulator training started. Both the students and the surgeons were instructed in a standardized manner on the function of the simulator. None of the students had previous experience with this or any other intraocular surgical simulator. One of the cataract surgeons had several years before been exposed to an intraocular surgical simulator for demonstration purposes only. The other six surgeons had not trained in an intraocular surgical simulator before.

Surgical simulator

To evaluate the study participants' cataract surgical skills, the intraocular surgical simulator, Eyesi, was used. This simulator has previously been described (Selvander & Asman 2010), and for this study, the cataract head with a model eye for cataract surgery was used. Probes are inserted into a model eye and a virtual binocular image is created. The image is shown through two oculars giving an image of the anterior segment. Software version 2.5 was used.

Three cataract modules and three manipulating modules were used. The level for each module was chosen based on a pilot study so that tasks would be difficult enough to enable discrimination based on surgical skill and be as close as possible to reality. Cataract modules: the capsulorhexis module (level four of ten) where the trainee has to inject viscoelastics into the anterior chamber, create a flap with a cystotome and pull the flap and perform a capsulorhexis with a forceps (Fig 1A); the hydromaneuvers module (level one of four) where the trainee has to make a hydrodissection of the lens and move the nucleus around to prove that a dissection has been obtained (Fig 1B); the phaco divide and conquer module (level five of six) where the trainee has to divide a nucleus into four quadrants and thereafter remove and emulsify each quadrant with the phaco probe (Fig. 1C). Manipulation modules: the cataract navigation training module (level two of three) where the trainee has to hold an instrument tip steady in mobile spheres scattered at different levels in the anterior chamber (Fig. 2A); the cataract forceps training module (level four of four) where the trainee has to move triangles lying on top of the lens into a fictive basket sitting in the middle of the anterior chamber (Fig. 2B); the cataract cracking and chopping module (level six of eight) where the trainee has to pull each end of a handle simultaneously thereby elongating it into a given length (Fig. 2C). Before using each new module, the trainee was shown an instructional video.

The tasks were performed at a single 60 min session in the above given order three times each except for the phaco divide and conquer module in which two iterations were performed. Several different performance parameters were calculated in the simulator scoring system. A summary parameter (overall score) was obtained for all iterations. For the second iteration, additional parameters were also obtained (Table 1).

The sessions on the simulator were video recorded as seen on the observer screen (Fig. 3). The video recordings from the second iteration of the capsulorhexis, hydromaneuvers and phaco divide and conquer modules were saved for later evaluation. Because of a technical error, the module hydromaneuvers was not recorded for one of the students. For all the other participants, the appropriate modules were recorded.

Video evaluation

The recorded video clips were analysed with regard to surgical skills with the Objective Structured Assessment of Cataract Surgical Skills (OSACSS) (Saleh et al. 2007) in applicable parts and a modified Objective Assessment of Surgical Skill (OSATS) (Ezra et al. 2009). Two experienced cataract surgeons, who were masked regarding the subjects' identity, evaluated the procedures. The OSACSS video anal-

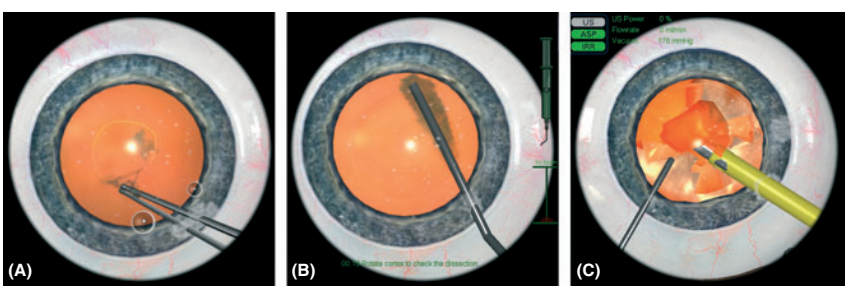


Fig. 1. Three cataract modules were used. (A) Capsulorhexis module: a capsulorhexis is performed, (B) hydromaneuvers module: hydrodissection is created and tested, (C) phaco divide and conquer module: phacoemulsification of the nucleus.

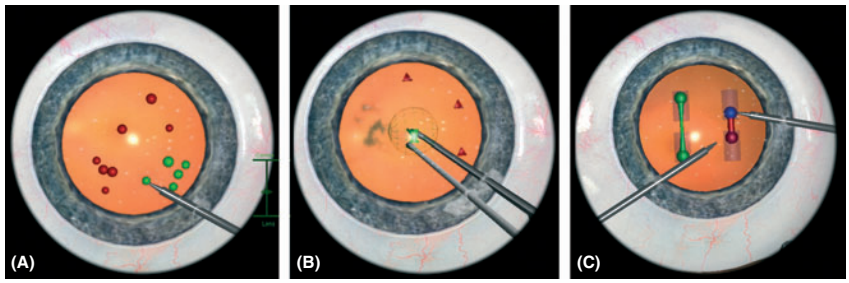


Fig. 2. Three manipulation modules were used (A) cataract navigation training: the trainee has to hold an instrument tip steady in mobile spheres scattered at different levels in the anterior chamber, (B) cataract forceps training: the trainee has to move triangles lying on top of the lens into a fictive basket sitting in the middle of the anterior chamber, (C) cataract cracking and chopping training: the trainee has to pull each end of a handle simultaneously thereby elongating it into a given length.

Table 1. Comparison of performance parameters between cataract surgeons and medical students' second iteration (median, range).

	Cataract surgeons	Medical students	p
Module: Capsulorhexis			
Overall score (of 100)	54 (0–75)	0 (0–78)	0.035*
Average radius of capsulorhexis value	2.27 (2.09–3.21)	2.43 (1.58–3.02)	0.589
Centering (distance rhexis centre to eye centre)	0.39 (0.04–0.49)	0.56 (0.27–2.19)	0.065
Deviation of rhexis radius from 2.5 mm	0.26 (0.08–0.71)	0.28 (0.01–0.92)	0.949
Injured cornea area value	0 (0–0.67)	0.56 (0–16.3)	0.048*
Maximum radial extension of capsulorhexis value	2.66 (2.57–3.73)	3.59 (2.5–4.62)	0.098
Roundness of capsulorhexis value	0.553 (0.01–0.71)	0 (0–0.95)	0.099
Time (with instruments inserted) duration (second)	118 (73–425)	170 (93–373)	0.153
Module: Hydromaneuvers			
Overall score (of 100)	86 (54–90)	81 (44–90)	0.503
Injured cornea area value	0 (0–0)	0 (0–0.57)	–**
Time (with instruments inserted) duration	21 (17–37)	25 (9–104)	0.408
Module: Phaco divide and conquer			
Overall score (of 100)	0 (0–95)	0 (0–76)	0.081
Injured cornea area value	0 (0–0.722)	0.204 (0–5.85)	0.086
Time (with instruments inserted) duration	337 (263–480)	399 (207–590)	0.092
Ultrasonic energy value	444 (341–743)	536 (117–883)	0.874
Ultrasonic leakage value	372 (238–608)	414 (105–994)	0.874
Emulsification near capsule no events	3 (0–6)	6 (0–22)	0.051
Posterior capsule torn no events	1 (0–5)	4 (0–10)	0.063
Successful cracking attempts value	2 (1–3)	0 (0–3)	0.014*
Module: Cataract navigation training			
Overall score (of 100)	57 (49–81)	55 (0–71)	0.307
Injured cornea area value	0 (0–0)	0 (0–5.61)	0.08
Instrument slipped out of sphere no. events	12 (7–31)	24 (7–53)	0.227
Odometer value	183 (123–315)	246.5 (110–460)	0.215
Time (with instruments inserted) duration	63 (49–91)	93 (41–480)	0.061
Module: Cataract forceps training			
Overall score (of 100)	93 (76–100)	76 (4–98)	0.03*
Injured cornea area value	0 (0–0)	0.0185 (0–5.61)	0.021*
Odometer value	81.5 (59.1–92.7)	98.5 (77.5–213)	0.008*
Time (with instruments inserted) duration	36 (20–40)	38 (21–59)	0.024*
Module: Cataract cracking and chopping training			
Overall score (of 100)	90 (78–98)	78 (1–98)	0.022*
Injured cornea area value	0 (0–0.185)	0 (0–5.02)	0.323
Instrument slipped out of sphere no. events	3 (1–13)	14 (1–37)	0.015*
Time (with instruments inserted) duration	24 (17–59)	58 (23–253)	0.016*
Injured lens area value	0 (0–0.305)	0.143 (0–4.64)	0.048*

*Statistical significance.
**Too many zeros allow for meaningful statistical analysis.

ysis of real cataract operations has construct validity for cataract surgical skill (Saleh et al. 2007). It has also been used to evaluate capsulorhexis procedures on the Eyesi system (Selvander & Asman 2010). The modified OSATS has been used for the evaluation of surgical skills in other surgical areas (Grantcharov et al. 2004) as well as in ophthalmic surgery (Ezra et al. 2009) and has also been used to score capsulorhexis procedures on the Eyesi system (Selvander & Asman 2010).

Statistical analysis

Differences in performance parameters between groups were tested for statistical significance using the Mann–Whitney *U*-test. Spearman correlation test was used to analyse correlation between the OSACSS and OSATS scores and the overall score given by the surgical simulator. Intraclass correlation coefficient was used to determine interrater reliability for the OSACSS and OSATS scoring.

Results

Cataract surgeons outperformed medical students with regard to overall score on the modules capsulorhexis ($p < 0.001$, $p = 0.035$, $p = 0.010$ for the tree iterations, respectively), cataract navigation training ($p = 0.024$, $p = 0.307$, $p = 0.007$), cataract forceps training ($p = 0.017$, $p = 0.03$, $p = 0.028$). Less obvious differences in overall score were found for modules cataract cracking and chopping training ($p = 0.266$, $p = 0.022$, $p = 0.324$) and phaco divide and conquer ($p = 0.011$, $p = 0.081$ for the two

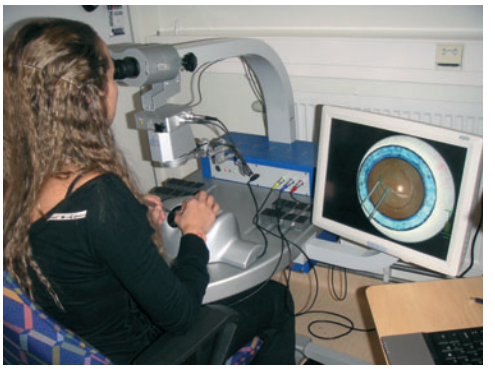


Fig. 3. A medical student training in the Eyesi intraocular virtual reality surgery simulator.

iterations, respectively). No differences in overall score were found on the hydromaneuvers module (p = 0.588, p = 0.503, p = 0.773) (Fig. 4).

Analysing the second iteration in detail, it could be noted that naïve trainees made more damage to the cornea (capsulorhexis, p = 0.048; cataract forceps training, p = 0.021) and lens (cataract cracking and chopping training p = 0.048) during training (Table 1). For the cataract forceps module, naive trainees had higher odometer and time duration value than the surgeons had (p = 0.008; p = 0.024) and during the phaco procedure, their cracking attempts were less successful (p = 0.014) (Table 1).

The difference between surgeons and students was also evident on the video evaluations of the capsulorhexis, hydromaneuvers and phaco procedures where surgeons received significantly higher and thus better scores from the evaluations of the modified OSATS (p = 0.001) and OSACSS (capsulorhexis, p = 0.003; hydromaneuvers, p = 0.017; phaco divide and conquer, p = 0.001) (Table 2).

Statistical analysis revealed significant correlations between the overall score given by the simulator and the video performance scores (OSACS) for capsulorhexis, hydromaneuvers and phaco (r = 0.669, p < 0.0001; r = 0.525, p = 0.010; r = 0.566, p = 0.004, respectively). Also, the modified OSATS score correlated significantly with the sum of overall score for the three modules above (r = 0.657, p = 0.001). Interrater reliability was high for OSACSS capsulorhexis (r = 0.788), phaco divide and conquer (r = 0.726) and OSATS (r = 0.764) and moderate for OSACSS hydrodissection (r = 0.598).

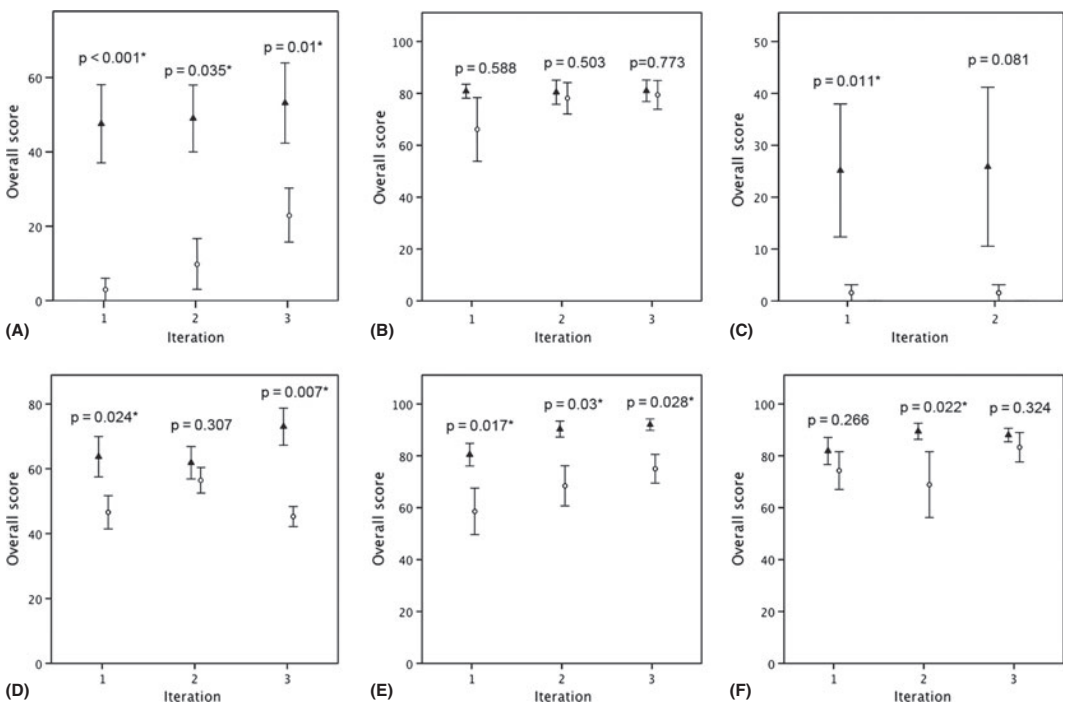


Fig. 4. Overall scores for cataract surgeons (solid triangles) and medical students (open circles) for modules (A) capsulorhexis, (B) hydromaneuvers, (C) phaco divide and conquer, (D) cataract navigation, (E) cataract forceps and (F) cataract cracking and chopping. Cataract surgeons generally outperformed medical students.

Table 2. Evaluation of recorded video clips from the second iteration of the modules capsulorhexis, hydromaneuvers and phaco divide and conquer (median, range). Scores based on the video evaluation tool OSACSS and OSATS. Maximum possible score in parenthesis.

	Cataract surgeons	Medical students	p
OSACSS Caps (15)	13.5 (8–14)	8 (5.5–13.5)	0.003*
OSACSS Hydro (5)	4 (3.5–5)	3 (1–5)	0.017*
OSACSS Phaco (25)	20.5 (15–23)	8.5 (5–22.5)	0.001*
OSATS (20)	17 (9.5–19.5)	5.5 (4–18)	0.001*

OSACSS = Objective Structured Assessment of Cataract Surgical Skill; OSATS = Objective Structured Assessment of Surgical Skill.
*Statistical significance.

Discussion

Not surprisingly, differences in performance scores were found between medical students and cataract surgeons in this study. The Eyesi intraocular surgical simulator has previously been validated as a scoring tool for some cataract surgical skills (Privett et al. 2010; Le et al. 2011). We showed that cataract surgeons outperform naïve subjects on the capsulorhexis module. These results are in accordance with the study from Privett et al. where they showed that surgeons had not only better scores but they also had less damage to the cornea, which are findings also supported in our study. Given the differences between cataract surgeons and naïve subjects, a level of proficiency for overall score and injured cornea area can be determined for the capsulorhexis procedure (Table 1).

We could also demonstrate construct validity for the phaco module, and to the best of our knowledge, this is the first report showing construct validity also for this specific module. There were significant differences for successful cracking attempts between surgeons and students. However, the overall score for experienced cataract surgeons was disappointingly low (median 4 and 0 of 100 for the first and second iterations, respectively), and only the first iteration was significantly better than the students'. Two reasons may account for this: (i) inherent shortcomings in the scoring system or (ii) the low number of participants and the heterogeneity in experience among surgeons. Excluding the two junior cataract surgeons would make the surgeon group more homogenous but did not change the overall score median values. Interestingly, comparing the video recordings of the phaco procedures between cataract surgeons and naïve subjects, there were no difficulties in distinguishing surgical skills. These facts indicate that the scoring system in the simulator may be more important of these two explanations pointing at a need for scoring refinement to better distinguish phaco skills. In that sense, the evaluation tools OSACSS and even OSATS are currently more accurate tools to evaluate surgical skill on the phaco module.

For the hydromaneuvers module, the surgeons could not score significantly better than the naïve subjects on the simulator. The material is considerably small and the group of surgeons is heterogeneous. The hydromaneuver was also performed on the lowest and easiest level and perhaps could not be challenging enough to allow separation between the two groups. These are factors that influence the results. However, the video evaluation easily distinguished the surgeons among the participants. Also, the correlation between the video evaluation scores and the simulator overall score was weak for this module. This suggests that the simulator scoring system needs further development also for this module to better distinguish cataract surgical skills.

Belyea et al. (2011) showed that training has an effect on surgical outcome even though their training curriculum was flexible and less controlled allowing for training both in anterior and posterior segment modules. Having found construct validity for three important modules (capsulorhexis, hydromaneuvers and phaco) for cataract surgery calls for the implementation of a structured simulator training programme. For this purpose, it is important to be able to assess the trainee and to measure progress in skills' training as well as to provide appropriate feedback (Kluger & DeNisi 1996; Mahmood & Darzi 2004). With this study, we can define levels of proficiency for the modules capsulorhexis and phaco based on the metrics from the simulator. Based on the scoring of the video recorded training, we can also set a level of proficiency for the hydromaneuvers procedure as well as the capsulorhexis and phaco procedure and for the three cataract procedures together. It is feasible because, after completion of a trial, the trainee can record the performance, and the video can subsequently be evaluated. While being a time-consuming procedure, it would be preferable to get this process automated via an improved scoring system in the simulator.

A limitation to our study is that it does not include residents. Le et al. (2011) showed a correlation between ophthalmic experience and total score in two manipulation modules (the forceps and antitremor modules). One might assume that similar correlations would exist also for other modules. However, Le et al. grouped their participants (medical students, residents and ophthalmic surgeons) based on level of general competence rather than surgical experience, thus causing overlap in surgical experience between groups. Their study participants also had shorter session times (20 min versus 60 min), and their participants were given only a brief orientation of the simulator. Our medical students were recruited during their ophthalmology rotation. They were thoroughly informed of important structures and important parts of the procedures. All study participants were shown voice-guided instructional videos pointing out important aspects before each new module was commenced. In this way, our naïve group is likely to be more similar to a group of residents without surgical experience.

Surgical simulation allows for training and testing in a safe and uniform manner. In this study, we have shown construct validity on several modules previously not investigated (phaco divide and conquer, hydromaneuvers, cataract cracking and chopping, cataract navigation training) on the Eyesi intraocular surgical simulator and confirmed previously demonstrated

construct validity for the capsulorhexis and cataract forceps training modules (Privett et al. 2010; Le et al. 2011). Interestingly, validation of the hydromaneuvers module required the somewhat tedious OSACSS video evaluation tool. Thus, a further development of the scoring system in the simulator for the hydromaneuvers module would be advantageous and make training and evaluation of progress more accessible and immediate.

Acknowledgements

This study was supported by grants from the Herman Järnhardt Foundation, Malmö, Sweden, the Medical Faculty, Lund University, Sweden, and the Foundation for Visually Impaired in Former Malmöhus län. The authors have no commercial or proprietary interest in the instrument described.

References

Belyea DA, Brown SE & Rajjoub LZ (2011): Influence of surgery simulator training on ophthalmology resident phacoemulsification performance. J Cataract Refract Surg **37**: 1756–1761.

Choi KS, Soo S & Chung FL (2009): A virtual training simulator for learning cataract surgery with phacoemulsification. Comput Biol Med **39**: 1020–1031.

Dooley IJ & O'Brien PD (2006): Subjective difficulty of each stage of phacoemulsification cataract surgery performed by basic surgical trainees. J Cataract Refract Surg **32**: 604–608.

Ezra DG, Aggarwal R, Michaelides M et al. (2009): Skills acquisition and assessment after a microsurgical skills course for ophthalmology residents. Ophthalmology **116**: 257–262.

Grantcharov TP, Kristiansen VB, Bendix J, Bardram L, Rosenberg J & Funch-Jensen P (2004): Randomized clinical trial of virtual reality simulation for laparoscopic skills training. Br J Surg **91**: 146–150.

Kluger A & DeNisi A (1996): The effects of feedback interventions on performance: a historical review, a meta-analysis, and a preliminary feedback intervention theory. Psychol Bull **119**: 254–284.

Laurell CG, Soderberg P, Nordh L, Skarman E & Nordqvist P (2004): Computer-simulated phacoemulsification. Ophthalmology **111**: 693–698.

Le TD, Adatia FA & Lam WC (2011): Virtual reality ophthalmic surgical simulation as a feasible training and assessment tool: results of a multicentre study. Can J Ophthalmol **46**: 56–60.

Mahmood T & Darzi A (2004): The learning curve for a colonoscopy simulator in the absence of any feedback: no feedback, no learning. Surg Endosc **18**: 1224–1230.

Mahr MA & Hodge DO (2008): Construct validity of anterior segment anti-tremor and forceps surgical simulator training modules: attending versus resident surgeon performance. J Cataract Refract Surg **34**: 980–985.

Privett B, Greenlee E, Rogers G & Oetting TA (2010): Construct validity of a surgical simulator as a valid model for capsulorhexis training. J Cataract Refract Surg **36**: 1835–1838.

Randleman JB, Wolfe JD, Woodward M, Lynn MJ, Cherwek DH & Srivastava SK (2007): The resident surgeon phacoemulsification learning curve. Arch Ophthalmol **125**: 1215–1219.

Saleh GM, Gauba V, Mitra A, Litwin AS, Chung AK & Benjamin L (2007): Objective structured assessment of cataract surgical skill. Arch Ophthalmol **125**: 363–366.

Selvander M & Asman P (2010): Virtual reality cataract surgery training: learning curves and concurrent validity. Acta Ophthalmol [Epub ahead of print].

Thijssen AS & Schijven MP (2010): Contemporary virtual reality laparoscopy simulators: quicksand or solid grounds for assessing surgical trainees? Am J Surg **199**: 529–541.

Received on November 16th, 2011.
Accepted on March 2nd, 2012.

Correspondence:
Dr Madeleine Selvander
Department of Clinical Sciences,
Malmö: Ophthalmology
Skåne University Hospital
S-205 02 Malmö
Sweden
Tel: + 46 40 338163
Fax: + 46 40 336212
Email: madeleine.selvander@skane.se

Paper II

Acta Ophthalmologica

Virtual reality cataract surgery training: learning curves and concurrent validity

Madeleine Selvander[1,2] and Peter Åsman[1]

[1]Department of Clinical Sciences, Lund University, Malmö: Ophthalmology, Sweden
[2]Centre for Medical Simulation, Skåne University Hospital, Malmö, Sweden

ABSTRACT.
Purpose: **To investigate initial learning curves on a virtual reality (VR) eye surgery simulator and whether achieved skills are transferable between tasks.**
Methods: **Thirty-five medical students were randomized to complete ten iterations on either the VR Caspulorhexis module (group A) or the Cataract navigation training module (group B) and then two iterations on the other module. Learning curves were compared between groups. The second Capsulorhexis video was saved and evaluated with the performance rating tool Objective Structured Assessment of Cataract Surgical Skill (OSACSS). The students' stereoacuity was examined.**
Results: **Both groups demonstrated significant improvements in performance over the 10 iterations: group A for all parameters analysed including score ($p < 0.0001$), time ($p < 0.0001$) and corneal damage ($p = 0.0003$), group B for time ($p < 0.0001$), corneal damage ($p < 0.0001$) but not for score ($p = 0.752$). Training on one module did not improve performance on the other. Capsulorhexis score correlated significantly with evaluation of the videos using the OSACSS performance rating tool. For stereoacuity < and ≥120 seconds of arc, sum of both modules' second iteration score was 73.5 and 41.0, respectively ($p = 0.062$).**
Conclusion: **An initial rapid improvement in performance on a simulator with repeated practice was shown. For capsulorhexis, 10 iterations with only simulator feedback are not enough to reach a plateau for overall score. Skills transfer between modules was not found suggesting benefits from training on both modules. Stereoacuity may be of importance in the recruitment and training of new cataract surgeons. Additional studies are needed to investigate this further. Concurrent validity was found for Capsulorhexis module.**

Key words: cataract surgery – simulator – skills training – virtual reality

Acta Ophthalmol. 2012: 90: 412–417
© 2010 The Authors
Acta Ophthalmologica © 2010 Acta Ophthalmologica Scandinavica Foundation

doi: 10.1111/j.1755-3768.2010.02028.x

Introduction

Learning cataract surgery is technically challenging and demands well-developed psychomotor skills (Binenbaum & Volpe 2006). Teaching cataract surgery is costly and time-consuming. The rate of complications is higher for surgeons under training compared to more experienced ones (Randleman et al. 2007).

Capsulorhexis is one of the most difficult skills for new cataract surgeons to master (Dooley & O'Brien 2006). Besides scarce wet-lab training, most new surgeons train in the operating room on real patients (Henderson & Ali 2007; Lee et al. 2007). It is desirable to move the initial increased risk training from the operating room.

Surgical simulators have long been used for training and assessment in other surgical disciplines and can improve operating skills (Seymour et al. 2002; Grantcharov et al. 2004; Ahlberg et al. 2007; Kundhal & Grantcharov 2009; Schijven et al. 2010). The EYESi simulator (VR Magic, Mannheim, Germany) is a commercially available virtual reality (VR) eye surgery simulator for training in both anterior and posterior segment intraocular surgery. The VR simulator provides metrics and scoring at the end of each performed task. These scores correlate with the experience of intraocular surgery indicating construct validity (Rossi et al. 2004; Mahr & Hodge 2008; Solverson et al. 2009) and VR training can improve capsulorhexis wet-laboratory performance (Feudner et al. 2009). Posterior segment VR training has been investigated but little is known regarding the learning curves associated with training on the simulator's anterior segment modules as well as the validity of the simulator's scoring system.

The aim of this study was to examine learning curves on the EYESi simulator anterior segment modules and whether achieved skills are transferable between tasks. Furthermore, we wanted to compare the performance score of the Capsulorhexis task on the simulator to a video-based scoring system of the same procedure.

Material and Methods

Thirty-five medical students at Skåne University hospital participated in the study (Table 1). They were attending the ophthalmology rotation at the 9th semester. All of them underwent simulator training. They received standard oral instructions by one test leader who also supervised all tasks. The students were shown a short instructional film incorporated in the simulator system, before performing each task on the simulator. Before commencing the simulator tasks, the students were screened for previous experience with eye surgery simulators as an exclusion criterion. Age was recorded for each student. After the simulator training, stereoacuity was measured using the TNO (Laméris Ootech BV, Nieuwegen, the Netherlands) charts plate V–VII. Informed consent was acquired from each student.

Table 1. Age and stereoacuity of participants.

	Group A (n = 17)	Group B (n = 18)
Age median (range)	25 (23–38)	26 (25–35)
TNO 30	5	4
TNO 60	9	12
TNO 120	1	1
TNO 480	0	0
TNO >480	2	1

EYESi simulator

The EYESi surgical simulator (software version 2.4) was used in the study. The simulator has software for training in both cataract and vitreoretinal surgery. It is provided with a virtual operating microscope, a model eye and handheld probes (forceps, cannula/cystotome, and pin) that are inserted into the model eye. It generates a virtual stereoscopic image through the oculars. The simulator comes with several different modules for cataract surgery, including both cataract-specific tasks such as capsulorhexis and phacoemulsification, as well as manipulation exercises. For each module, there are several levels with progressive difficulty. The simulator calculates a performance score between 0 and 100 for each iteration and gives metrics providing feedback on microscope handling, tissue treatment, target achievement, efficiency and instrument handling. Written or oral momentary simulator feedback is available if wanted. At task completion, the entire task sequence can be saved on a USB-stick for later use.

The participants in the study were tested on the Cataract navigation training module on level three of three (Fig. 1). Here, the trainee has to hold an instrument steady in spheres spread in the anterior chamber. The challenge is to be able to efficiently manoeuvre the instrument in the anterior chamber and hold it still in each sphere. We also used the Capsulorhexis module level four (of 10), where the trainee has to inject viscoelastics through a cannula, with a cystotome make a commencement of a capsulorhexis flap, and finally with a forceps form and complete a circular capsulorhexis (Fig. 1). Metric data collected in this study were parameters that were mutual for the two modules: overall score, procedure time with instrument inserted, injured cornea area value, injured lens area value, iris contact score, incision stress value and for the Capsulorhexis module also the parameters centring and roundness.

The students were randomly divided into two groups, A and B (Fig. 2). Each student in group A performed

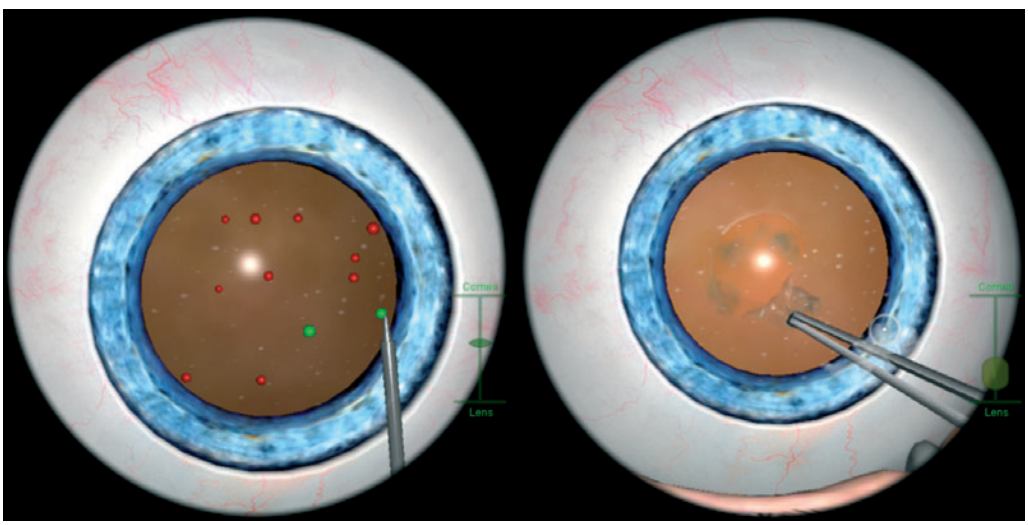


Fig. 1. EYESi virtual reality simulator modules for anterior segment surgery. Cataract navigation training module (left): the trainee has to insert and hold an instrument steady in spheres that are spread in the anterior chamber. Capsulorhexis module (right): the trainee has to form and complete a capsulorhexis.

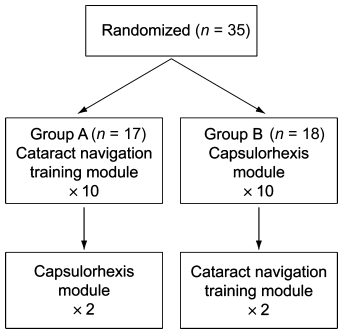


Fig. 2. Study set-up. Training on one module (10 iterations) was immediately followed by two iterations on the other module at the same session.

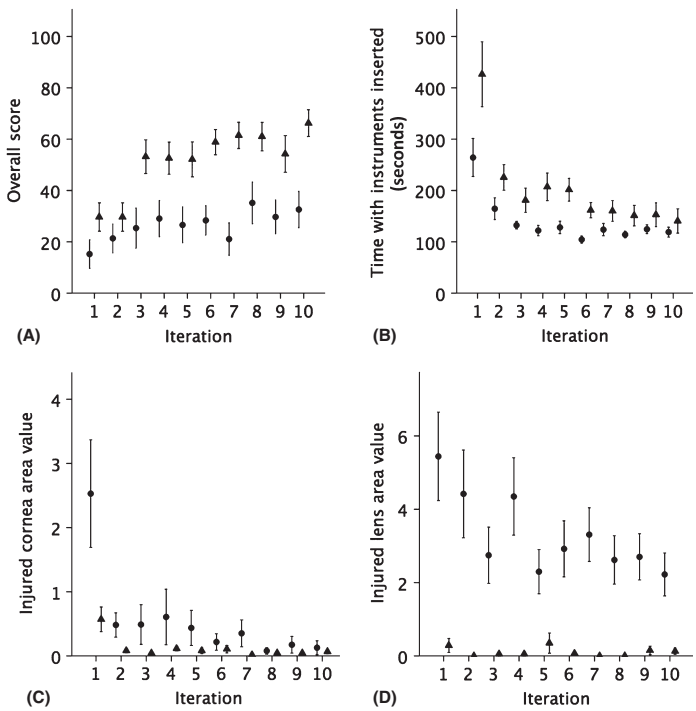


Fig. 3. Initial learning curves for Capsulorhexis module (*circles*) and Cataract navigation training module (*triangles*). (A) Improvement over the ten iterations for capsulorhexis overall score was not significant $p = 0.752$ but score at the 10th iteration was significantly higher than at the 1st iteration ($p = 0.047$). For Cataract navigation, training improvement over the 10 iterations was significant $p = 0.004$ reaching a plateau at third iteration. (B) Time with instruments inserted decreased significantly for both modules $p < 0.0001$, plateau reached at third iteration. (C) Injured cornea area value decreased for Capsulorhexis module $p < 0.0001$ reaching a plateau at sixth iteration and for Cataract navigation training ($p = 0.0003$) reaching a plateau at seventh iteration. (D) Injured lens area value for capsulorhexis did not decrease significantly over the 10 iterations ($p = 0.336$) but was significantly lower at the 10th iteration when compared with the 1st $p = 0.022$. Injured lens area value for cataract navigation decreased significantly $p = 0.0033$ but did not reach a plateau.

10 iterations on the Cataract navigation training module and thereafter two iterations on the Capsulorhexis module. The students in group B started with ten iterations on the Capsulorhexis module and then two iterations on the Cataract navigation training module. The second iteration on the Capsulorhexis for each student was recorded, and the video was saved for later evaluation. Five videos were not recorded (two from group A and three from group B); a corrupt USB memory card made three videos non-viewable and the tenth instead of the second video was recorded for two individuals.

Simulator film evaluation

The saved videos from the second Capsulorhexis were evaluated by a cataract surgeon according to the cataract performance rating tool Objective Structured Assessment of Cataract Surgical Skill (OSACSS) in applicable parts (Saleh et al. 2007). The simulator videos were also evaluated using the video-based modified Objective Structured Assessment of Technical Surgical Skills (OSATS) scoring system (Martin et al. 1997; Grantcharov et al. 2004) that has shown an ability to distinguish different levels of technical surgical skill in other ophthalmology areas (Ezra et al. 2009). The evaluator was masked regarding the simulator score, student and study group. The evaluation scores were correlated with the simulator performance score on the Capsulorhexis module. Correlation between the evaluation scores and the simulator performance score on the Capsulorhexis module were analysed.

Statistical analysis

The Friedman test was used for analyzing the learning curves. Multiple comparisons were made to identify when plateau of learning had occurred. Spearman correlation test was used to analyse the correlation between the visual evaluation of the capsulorhexis simulator videos and the simulator performance score. For the comparisons between groups A and B, the second iteration of Cataract navigation training and Capsulorhexis was analysed for each parameter with the Mann–Whitney

Table 2. Comparison between groups A and B, iteration #2 (median, range).

Parameter	Group A	Group B	p-value
Cataract navigation training module			
Overall score (points)	51 (0–78)	46 (0–78)	0.364
Time with instruments inserted (seconds)	202 (78–448)	272 (84–639)	0.291
Incision stress value	0.0 (0–8.0)	0.0 (0.0–136.0)	0.106
Injured cornea area value	0.0 (0.0–0.4)	0 (0.0–1.8)	0.296
Injured lens area value	0.0 (0.0–0.0)	0.0 (0.0–0.73)	0.163
Iris contact value	0.0 (0.0–1.4)	0.0 (0.0)	0.303
Capsulorhexis module			
Overall score (points)	0 (0–93)	7.5 (0–56)	0.773
Time with instruments inserted (seconds)	114 (67–275)	141 (73–435)	0.151
Incision stress value	0.0 (0.0–5.7)	0.0 (0.0–2.26)	0.119
Injured cornea area value	0.1 (0.0–4.4)	0.2 (0.0–9.5)	0.763
Injured lens area value	1.5 (0.0–12.7)	2.2 (0.0–18.1)	0.817
Iris contact value	0.0 (0.0–0.9)	0.0 (0.0–0.2)	0.080
Score	**Group A**	**Group B**	**p-value**
Evaluation of video-recorded Capsulorhexis			
Evaluation OSACSS (points)	8 (6–11)	8 (5–10)	0.64
Evaluation modified OSATS (points)	7 (4–13)	10 (4–13)	0.52

OSACSS, objective structured assessment of cataract surgical skill; OSATS, objective structured assessment of technical surgical skills.

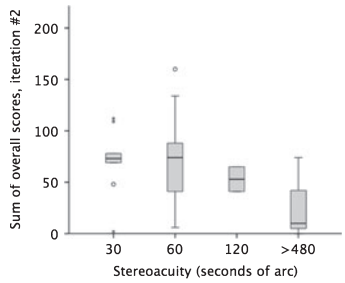


Fig. 4. Sum of overall scores for second iteration on both Capsulorhexis and Cataract navigation training modules for various levels of stereoacuity. Median = thick horizontal line, boxes = 25 and 75% percentiles, whiskers = 10 and 90% percentiles.

U-test. Mann–Whitney *U*-test was used to compare median score between individuals with stereoacuity 60 seconds of arc or better and 120 seconds of arc or worse. A level of $p < 0.05$ was considered statistically significant.

Results

Both group A (Cataract navigation training module) and group B (Capsulorhexis module) demonstrated significant improvements in performance over the ten iterations (Fig. 3). Improvement for capsulorhexis overall score was not significant $p = 0.752$ even though a significant difference could be detected comparing the first and last iteration (iteration 1 versus 10 $p = 0.047$, Wilcoxon). For the cataract navigation training, improvement in overall score was marked ($p = 0.004$) reaching a plateau at the third iteration. Time with instruments inserted decreased significantly for both modules $p < 0.0001$, plateau reached at the third iteration. Injured cornea area value decreased for capsulorhexis ($p < 0.0001$) reaching a plateau at the sixth iteration, and for cataract navigation training ($p = 0.0003$) reaching a plateau at the seventh iteration. The injured lens area value decreased but did not reach a plateau for the Cataract navigation training module ($p = 0.0033$). Injured lens area value for capsulorhexis was significantly lower at the 10th iteration when compared to the 1st ($p = 0.022$, Wilcoxon) but a significant learning curve could not be demonstrated during the ten iterations ($p = 0.336$). No significant improvement was observed for the specific capsulorhexis parameters centring and roundness ($p = 0.091$ and $p = 0.873$). For the parameters incision stress value and iris contact value, there were too few nonzero events on both the Capsulorhexis module and the Cataract navigation training module to allow for meaningful statistical analyses related to improvement.

The simulator overall score on the Capsulorhexis module had a significant positive correlation with the modified OSATS score ($r^2 = 0.59$, $p < 0.0001$) and with the OSACSS score ($r^2 = 0.704$, $p < 0.0001$).

There was no significant difference in performance between groups A and B when comparing the second iteration of Cataract navigation training module (Table 2). Likewise, we could not detect any significant difference for the Capsulorhexis module between the groups. Comparing the evaluations of the simulator video recordings, there was no significant difference in evaluation score between groups A and B (Table 2).

The median value for the sum of overall score for the second iteration of Capsulorhexis and Cataract navigation training modules was 73.5 for individuals with stereoacuity 60 seconds of arc or better, and 41.0 for those with stereoacuity 120 seconds of arc or worse. This difference was however not statistically significant ($p = 0.062$, Mann–Whitney) (Fig. 4).

No student had previous experience with eye surgery simulators.

Discussion

Our study has demonstrated the initial learning curves for two different modules on the EYESi ophthalmic intraocular surgery simulator. A plateau for overall score as well as for time occurred after very few iterations on the Cataract navigation training module. Similar results have been reported for individuals more experienced in ophthalmology such as residents and experienced surgeons (Mahr & Hodge 2008). Rapid learning is common for other surgical simulator tasks as well (Park et al. 2007). Simulator training has shown to be beneficial in early clinical performance in other medical fields such as colonoscopy (Park et al. 2007) and laparoscopic surgery (Seymour et al. 2002). Seymour et al. (2002) showed that tissue damage such as injury and burns were five times more likely to occur in the non-trained group compared to the VR-trained group. On both our studied modules, the students learned how to more efficiently and cautiously handle instrument inside the model eye. The simulator therefore has the potential to be part of the initial training of new cataract surgeons.

The capsulorhexis procedure is considered to be one of the most difficult steps in a cataract operation (Dooley & O'Brien 2006). The trainee has to focus attention on both the instrument and on the rhexis formation. It is thus likely that considerably more training than 10 iterations is needed to reach a level of proficiency. In our study, the trainees reached a plateau regarding time but not regarding overall score. The overall score parameter includes quality parameters of the final rhexis and is a better representative of capsulorhexis skill acquisition than time. In the report by Feudner et al. (2009) designed to improve capsulorhexis wet-laboratory performance, all students (30 persons) and 29 of 32 residents were able to reach a score level of 90 of 100 after two training sessions. Each session included two rounds of nine different tasks, and four of them were capsulorhexis simulation tasks. They also showed that this training improved the performance of capsulorhexis wet-laboratory procedure. However, considering that experienced surgeons reached only a disappointing 155 of possible 300 score in a report from Le et al. (2008) where they also included the Capsulorhexis procedure, a lower performance goal might well be enough and time efficient to strive for. (In that report, experienced surgeons performed the Capsulorhexis task in conjunction with two manipulating tasks, significantly better compared to novices at initial practice.) More studies are needed to establish a true level of proficiency for experienced cataract surgeons and how many iterations in general a novice would need to reach that level. As a comparison, on a laparoscopy simulator participants receptive to training needed an average of 25 iterations to reach proficiency (Schijven & Jakimowicz 2004).

The set-up of training is important. Ten iterations on the same level is probably not the most efficient learning. Instead, gradually increasing difficulty, termed 'shaping' in the behavioural literature, has been suggested as one methodology of training (Gallagher et al. 2005). On the other hand, the increments have to be sufficiently large to be enough challenging to give an efficient training (Ali et al. 2002). As is noticed in our material, skills at baseline vary between individuals and we could see that some individuals with bad stereoacuity had difficulties in improving their performance score. Others have shown that previous computer experience and visuo-spatial skills affect performance on VR surgery simulators (Hassan et al. 2007; Rosser et al. 2007). Schijven & Jakimowicz (2004) found in their study one group that did not benefit from training despite their low initial scores and in ophthalmology, it has been reported that around 10% of residents have difficulties in learning surgical skills (Binenbaum & Volpe 2006). Considering these facts, individualized training towards a level of proficiency is desired. This is supported by research regarding learning of motor skills where self-controlled practice leads to more effective training (Wulf et al. 2010). To the best of our knowledge, no previous studies on the EYESi anterior segment modules have included more than five iterations of the same module on the same level. More studies are therefore needed to further investigate the capsulorhexis learning curve and training conditions.

Simulator overall score correlated with the OSACSS evaluation score. Because this evaluation tool has demonstrated construct validity for video-based evaluations of real cataract operations (Saleh et al. 2007), it strengthens the validity of the scoring system in the simulator. In a similar manner, we found a correlation also for the video-based modified OSATS scoring system. To our knowledge, this scoring system has not been used before to evaluate intraocular operations, but has shown an ability to distinguish technical surgical skill in ophthalmic microsurgery (Ezra et al. 2009). The OSATS scoring system is also widely used in video-based assessment in other surgical areas (Kundhal & Grantcharov 2009; Schijven et al. 2010).

Our study subjects all took a stereoacuity test. The estimated statistical power after grouping stereoacuity in <120 seconds of arc and ≥ 120 seconds of arc was, however, too low ($<80\%$) to make any definite conclusions regarding effects on performance. Rossi et al. (2004) demonstrated that stereopsis correlated with performance in vitreoretinal simulation. A confounding factor in their study was however that those subjects with vitreoretinal experience had a better stereoacuity. We believe, however, that good stereoacuity would probably be an advantage in cataract surgery. Noteworthy, two of the three students with TNO >480 (one from group A and one from group B) scored zero points on seven and eight of their first 10 attempts on the simulator. This study was not designed to investigate the different performances depending on stereoscopic vision but it gives an indication on its importance in intraocular surgery. This factor may have large impact in the recruitment and training of new cataract surgeons. Additional studies are needed, however, to investigate this further.

In conclusion, when training on the EYESi simulator, the trainees quickly learned how to more efficiently and cautiously handle instruments inside the model eye. The simulator therefore has the potential to be part of the initial training of new cataract surgeons and it would be beneficial to train on both modules. However, the structure of training, especially for more complex tasks like capsulorhexis, demands for an individualization of training. Our experience with individuals with poor stereoacuity supports this strategy and might be of large impact in the recruitment and training of new cataract surgeons. Further studies are needed to optimize training programs and make them time efficient.

Acknowledgments

This study was supported by a grant from the Herman Järnhardt Foundation, Malmö, Sweden. The authors have no commercial or proprietary interest in the instrument described.

References

Ahlberg G, Enochsson L, Gallagher AG et al. (2007): Proficiency-based virtual reality training significantly reduces the error rate for residents during their first 10 laparoscopic cholecystectomies. Am J Surg **193**: 797–804.

Ali MR, Mowery Y, Kaplan B & DeMaria EJ (2002): Training the novice in laparoscopy. More challenge is better. Surg Endosc **16**: 1732–1736.

Binenbaum G & Volpe NJ (2006): Ophthalmology resident surgical competency: a

national survey. Ophthalmology **113**: 1237–1244.

Dooley IJ & O'Brien PD (2006): Subjective difficulty of each stage of phacoemulsification cataract surgery performed by basic surgical trainees. J Cataract Refract Surg **32**: 604–608.

Ezra DG, Aggarwal R, Michaelides M et al. (2009): Skills acquisition and assessment after a microsurgical skills course for ophthalmology residents. Ophthalmology **116**: 257–262.

Feudner EM, Engel C, Neuhann IM, Petermeier K, Bartz-Schmidt KU & Szurman P (2009): Virtual reality training improves wet-lab performance of capsulorhexis: results of a randomized, controlled study. Graefes Arch Clin Exp Ophthalmol **247**: 955–963.

Gallagher AG, Ritter EM, Champion H, Higgins G, Fried MP, Moses G, Smith CD & Satava RM (2005): Virtual reality simulation for the operating room: proficiency-based training as a paradigm shift in surgical skills training. Ann Surg **241**: 364–372.

Grantcharov TP, Kristiansen VB, Bendix J, Bardram L, Rosenberg J & Funch-Jensen P (2004): Randomized clinical trial of virtual reality simulation for laparoscopic skills training. Br J Surg **91**: 146–150.

Hassan I, Gerdes B, Koller M, Dick B, Hellwig D, Rothmund M & Zielke A (2007): Spatial perception predicts laparoscopic skills on virtual reality laparoscopy simulator. Childs Nerv Syst **23**: 685–689.

Henderson BA & Ali R (2007): Teaching and assessing competence in cataract surgery. Curr Opin Ophthalmol **18**: 27–31.

Kundhal PS & Grantcharov TP (2009): Psychomotor performance measured in a virtual environment correlates with technical skills in the operating room. Surg Endosc **23**: 645–649.

Le T, Adatia FA, Gupta R, Buhrmann R, O'Connor M & Lam WC (2008): Evaluating a virtual cataract surgical simulator as a potential objective assessment tool in ophthalmic surgery. Open Med **2** (Suppl): 54–55.

Lee AG, Greenlee E, Oetting TA et al. (2007): The Iowa ophthalmology wet laboratory curriculum for teaching and assessing cataract surgical competency. Ophthalmology **114**: e21–e26.

Mahr MA & Hodge DO (2008): Construct validity of anterior segment anti-tremor and forceps surgical simulator training modules: attending versus resident surgeon performance. J Cataract Refract Surg **34**: 980–985.

Martin JA, Regehr G, Reznick R, MacRae H, Murnaghan J, Hutchison C & Brown M (1997): Objective structured assessment of technical skill (OSATS) for surgical residents. Br J Surg **84**: 273–278.

Park J, MacRae H, Musselman LJ, Rossos P, Hamstra SJ, Wolman S & Reznick RK (2007): Randomized controlled trial of virtual reality simulator training: transfer to live patients. Am J Surg **194**: 205–211.

Randleman JB, Wolfe JD, Woodward M, Lynn MJ, Cherwek DH & Srivastava SK (2007): The resident surgeon phacoemulsification learning curve. Arch Ophthalmol **125**: 1215–1219.

Rosser JC Jr, Lynch PJ, Cuddihy L, Gentile DA, Klonsky J & Merrell R (2007): The impact of video games on training surgeons in the 21st century. Arch Surg **142**: 181–186.

Rossi JV, Verma D, Fujii GY, Lakhanpal RR, Wu SL, Humayun MS & De Juan E Jr (2004): Virtual vitreoretinal surgical simulator as a training tool. Retina **24**: 231–236.

Saleh GM, Gauba V, Mitra A, Litwin AS, Chung AK & Benjamin L (2007): Objective structured assessment of cataract surgical skill. Arch Ophthalmol **125**: 363–366.

Schijven MP & Jakimowicz J (2004): The learning curve on the Xitact LS 500 laparoscopy simulator: profiles of performance. Surg Endosc **18**: 121–127.

Schijven MP, Reznick RK, ten Cate OT, Grantcharov TP, Regehr G, Satterthwaite L, Thijssen AS & MacRae HM (2010): Transatlantic comparison of the competence of surgeons at the start of their professional career. Br J Surg **97**: 443–449.

Seymour NE, Gallagher AG, Roman SA, O'Brien MK, Bansal VK, Andersen DK & Satava RM (2002): Virtual reality training improves operating room performance: results of a randomized, double-blinded study. Ann Surg **236**: 458–463.

Solverson DJ, Mazzoli RA, Raymond WR, Nelson ML, Hansen EA, Torres MF, Bhandari A & Hartranft CD (2009): Virtual reality simulation in acquiring and differentiating basic ophthalmic microsurgical skills. Simul Healthc **4**: 98–103.

Wulf G, Shea C & Lewthwaite R (2010): Motor skill learning and performance: a review of influential factors. Med Educ **44**: 75–84.

Received on May 22nd, 2010.
Accepted on September 11th, 2010.

Correspondence:
Dr Madeleine Selvander
Department of Clinical Sciences,
Malmö: Ophthalmology
Skåne University Hospital
S-205 02 Malmö
Sweden
Tel: + 46 40 338163
Fax: + 46 40 336212
Email: madeleine.selvander@skane.se

Paper IV

Stereoacuity and intraocular surgical skill: Effect of stereoacuity level on virtual reality intraocular surgical performance

Madeleine Selvander, MD, Peter Åsman, PhD

PURPOSE: To evaluate the effect of stereoacuity on various intraocular surgical skills in inexperienced medical students using a virtual reality intraocular surgical simulator.

SETTING: Department of Clinical Sciences, Malmö: Ophthalmology, Skåne University Hospital, Malmö, Sweden.

DESIGN: Comparative case series.

METHODS: Ninth-semester medical students performed 1 iteration on each of the following 3 cataract training modules: navigation, forceps, and capsulorhexis. Before the simulator training, the trainees received standardized instructions and were allowed to perform 1 training round on the cataract navigation training module. After completion of the training, the level of stereoacuity was measured using TNO charts. Surgical performance for each task was measured, and performance parameter scores were recorded.

RESULTS: The study included 70 students. The simulator performance score correlated with the level of stereoacuity for the navigation training module (Spearman $r = 0.377$, $P = .001$) and forceps training module (Spearman $r = 0.306$, $P = .01$), showing a gradual increase in surgical performance with increasing stereoacuity. No such relationship was found for the capsulorhexis module (Spearman $r = 0.18$, $P = .136$).

CONCLUSIONS: A gradual detrimental effect on initial intraocular surgical skill with decreasing stereoacuity was shown. This calls for studies of the impact of deficient stereopsis on long-term training effects.

Financial Disclosure: Neither author has a financial or proprietary interest in any material or method mentioned.

J Cataract Refract Surg 2011; 37:2188–2193 © 2011 ASCRS and ESCRS

Training new cataract surgeons is an important assignment. New surgeons have higher complication rates.[1] Approximately 10% of residents under training have difficulties mastering intraocular surgery.[2] Cataract extraction is performed under a surgical microscope, generating a stereoscopic image through the oculars. Recently, a person's stereoacuity has attracted interest in terms of his or her suitability for surgery.[3,4,A] One study[5] found that reduced binocular vision led to inferior performance on a simple grasping exercise. Barry et al.[6] found that patients with strabismus and without stereoacuity performed worse on a laparoscopic training device than those without strabismus and with normal stereoacuity. Sachdeva and Traboulsi[7] found that patients with reduced stereoacuity performed worse than patients with normal stereoacuity on an intraocular surgical simulator.

Although strabismic patients are not physicians, those with deficient stereoacuity might be found among medical students, as well as among practicing ophthalmologists and surgeons. Whether the level of stereoacuity is relevant for individuals eligible for intraocular surgical profession has not been fully assessed, and none of the studies of intraocular surgery simulators[8,9] reports a more detailed correlation between stereoacuity and performance.

The aim of this study was to determine whether stereoacuity influences initial microsurgical skill in medical students who, by definition, would have a higher likelihood of wishing to become intraocular surgeons. We also wanted to see whether there was

 © 2011 ASCRS and ESCRS
Published by Elsevier Inc.

0886-3350/$ - see front matter
doi:10.1016/j.jcrs.2011.05.048

a correlation between the level of stereoacuity and performance. Finally, we wanted to evaluate whether there were differences in performance on the simulator between men and women.

SUBJECTS AND METHODS

This study enrolled medical students in their ninth semester who were on ophthalmology rotation. Before the simulator training, the students were given a standardized orientation on important anterior chamber structures and on the function of the simulator. Informed consent was acquired before the study started.

Surgical Simulator

The Eyesi intraocular surgical simulator for cataract surgery (VRmagic Holding AG) and the simulator's cataract head were used. As previously described,[9] this simulator consists of a model eye into which probes are inserted. A virtual binocular image is created and shown through 2 oculars, giving a stereoscopic virtual image of the anterior segment.

In this study, 3 training modules were used. The first was the cataract navigation training module on level 3, on which the trainee must insert and keep an instrument tip steady in small spheres of varying sizes scattered randomly in the anterior chamber (Figure 1, *A*). The second was the cataract forceps training module on level 3, on which the trainee must grasp small triangles laying on the top of the lens and move them to a fictive basket (Figure 1, *B*). The third was the capsulorhexis module on level 1, on which the trainee must create a capsulorhexis from a preformed flap (Figure 1, *C*). For each module, the simulator provides summary scores for different parameters. In this study, the parameters' overall score, time with instruments inserted, injured cornea area value, and injured lens area value were recorded for all 3 modules. For the cataract navigation training, the completed-objects parameter was also recorded.

Each student performed 1 initial iteration on the cataract navigation training module to become familiarized with the simulator. The student thereafter performed 1 iteration of the cataract navigation training, cataract forceps training, and capsulorhexis modules in that order. Before each new module, the student was shown an instructional video. After the simulator training, the student's stereoacuity was measured using TNO chart plates V to VII (Laméris Ootech BV).

Submitted: March 9, 2011.
Final revision submitted: May 24, 2011.
Accepted: May 25, 2011.

From the Department of Clinical Sciences (Selvander, Åsman), Lund University, Malmö: Ophthalmology, and the Centre for Medical Simulation (Selvander), Skåne University Hospital, Malmö, Sweden.

Supported by a grant from the Herman Järnhardt Foundation, Malmö, Sweden, and a grant from Lund University.

Corresponding author: Madeleine Selvander, MD, Department of Ophthalmology, Skåne University Hospital, S-205 02 Malmö, Sweden. E-mail: madeleine.selvander@skane.se.

Statistical Analysis

The Spearman correlation test (r value) was used to analyze the correlation between stereoacuity and performance parameters and between age and performance parameters. The Mann-Whitney U test was used to test for differences between male students and female students.

RESULTS

Seventy medical students were enrolled in the study. Table 1 shows the students' age and stereoacuity results by sex.

Surgical performance was affected by stereoacuity level (Figure 2), with a decrease appearing with minor stereoacuity defects. The effect became more pronounced as stereoacuity worsened. The overall simulator score correlated with the TNO value for the cataract navigation training module ($r = 0.377$, $P = .001$) and cataract forceps training module ($r = 0.306$, $P = .01$) but not for the capsulorhexis module ($r = 0.18$, $P = .136$) (Table 2). The number of completed objects correlated with the TNO value ($r = 0.401$, $P = .001$, Table 2). Time with instruments inserted, injured cornea area value, and injured lens area value did not correlate with the TNO value for any of the modules (Table 2).

There was no statistically significant difference in the performance of men and women on any parameter (Table 3). Age did not correlate with TNO values ($r = 0.070$, $P = .565$).

DISCUSSION

The intraocular surgical simulator used in this study has been validated as a scoring tool for cataract surgical skills,[10,11] and initial learning curves have been determined.[9] It has been shown that the level of stereoacuity affects fine motor skills in children.[12] Barry et al.[6] found that for strabismic patients, performance on a laparoscopic training device was related to the level of stereoacuity. This finding is consistent with a report by Rossi et al.,[8] who found better performance on an intraocular surgical simulator for the posterior segment by individuals with better stereoacuity. A confounding factor in their study was that the experienced surgeons also had better stereoacuity. Sachdeva and Traboulsi[7] report better initial performance scores for individuals with normal stereoacuity than for those with deficient stereoacuity. Their study used the same intraocular surgical simulator in a group of patients with varying age and stereoacuity; however, they did not find correlations between the level of stereoacuity and performance beyond a crude dichotomous scoring of stereoacuity. Our results confirm their findings and also show a gradual effect in which surgical difficulty increased with decreasing stereoacuity. An important difference between our study and that of Sachdeva

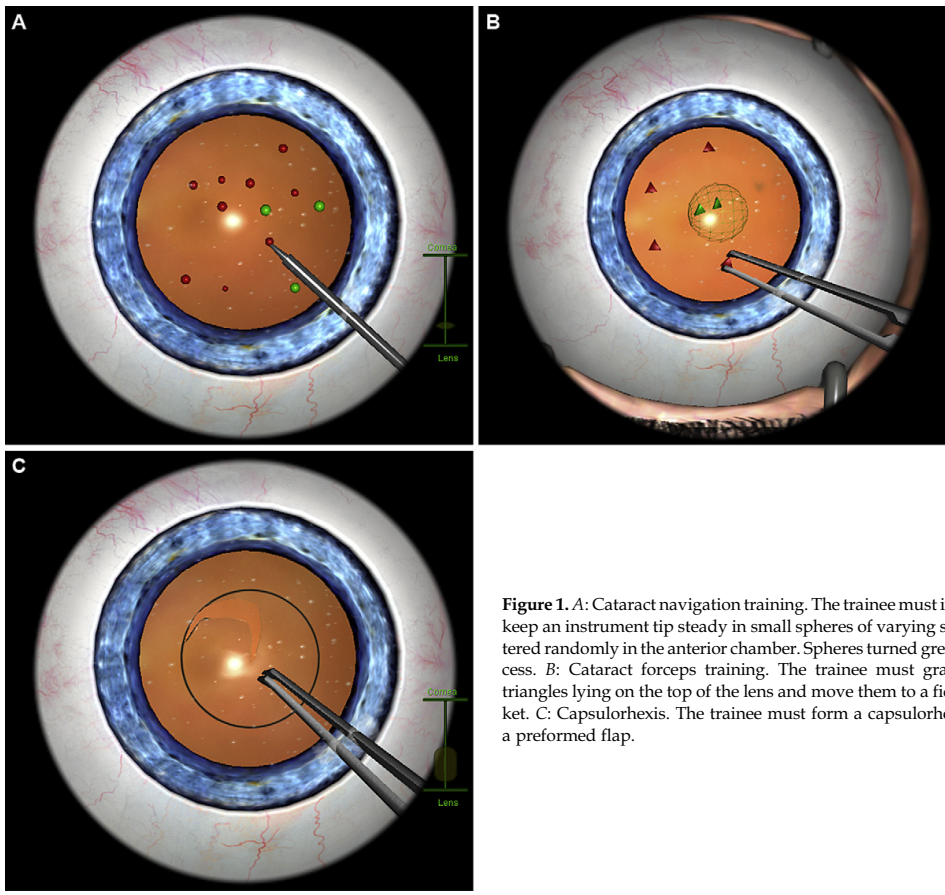


Figure 1. *A*: Cataract navigation training. The trainee must insert and keep an instrument tip steady in small spheres of varying sizes scattered randomly in the anterior chamber. Spheres turned green at success. *B*: Cataract forceps training. The trainee must grasp small triangles lying on the top of the lens and move them to a fictive basket. *C*: Capsulorhexis. The trainee must form a capsulorhexis from a preformed flap.

and Traboulsi is that we studied medical students instead of ophthalmic patients. Thus, our population was more homogenous in age and more likely than patients in an ophthalmology clinic to become surgeons. It would be expected that the motivation to participate in a study and to perform surgical tasks was different between the 2 cohorts as well.

Table 1. Student stereoacuity and age by sex.

Parameter	Men (n = 36)	Women (n = 34)
TNO plate (arcsec)		
30	7	8
60	15	19
120	4	5
240	2	2
480	3	0
>480	5	0
Age (y)		
Median	27	26
Range	22, 52	22, 36

We found a correlation on the 2 manipulating modules of cataract navigation training and cataract forceps training, but not on the capsulorhexis module. Capsulorhexis was performed on the easiest level, whereas the other 2 modules were performed on the highest level of difficulty. Perhaps the capsulorhexis level was too easy to be able to discriminate differences based on different stereoacuity. It could also be that the capsulorhexis procedure is complex and that other factors (eg, understanding of tissue behavior, 2-dimensional visual clues) compensate and give enough support for handling the task despite compromised stereoacuity, especially on the easiest first level.

Studies of the effects of a person's sex on surgical simulator skills are so far inconclusive. Shane et al.[13] report a difference in performance between men and women on a laparoscopic surgical simulator. Others

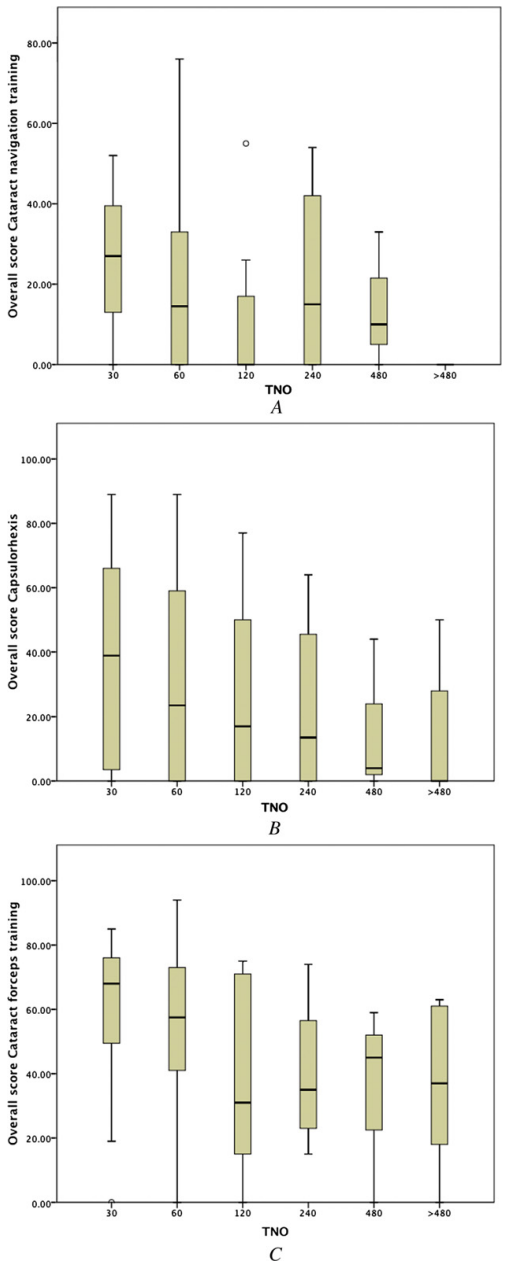


Figure 2. Overall score for various levels of stereoacuity.

found no differences on surgical simulators between the sexes.[14,15] In our considerably larger study group, we did not find differences in any parameter between the 2 sexes, implying that sex effects are negligible in early anterior surgical segment training.

Table 2. Correlation between performance parameters and stereoacuity (TNO).

Module/Parameter	*r* Value	*P* Value
Cataract navigation training		
Overall score	0.377	.001*
Time with instrument inserted	−0.162	.182
Injured cornea area value	−0.113	.351
Injured lens area value	−0.169	.44
Completed objects	0.401	.001*
Cataract forceps training		
Overall score	0.306	.01*
Time with instrument inserted	−0.075	.538
Injured cornea area value	−0.183	.13
Injured lens area value	−0.076	.604
Capsulorhexis		
Overall score	0.18	.136
Time with instrument inserted	−0.028	.819
Injured cornea area value	−0.146	.226
Injured lens area value	—†	—†

*Statistically significant
†Too many zero events to allow statistical comparison

Patient safety issues during the training of cataract surgeons have become an increasing concern.[3,16] In the cataract community, there is an ongoing discussion of the relevance of stereoacuity.[3,A] Of the countries that are members of the Organisation for Economic Co-operation and Development, only the Czech Republic requires binocular vision to perform ophthalmic surgery and The Netherlands is the only country that tests aspiring ophthalmology residents for stereopsis.[3] Such bold regulations must be carefully supported by scientific data. It is therefore important to emphasize that neither our data nor, to our knowledge, previously published studies provide valid support in surgeon-selection decisions based on stereoacuity because they relate only to basic initial training. We do not know whether these initial effects are diluted with training or remain relevant.

Suleman et al.[4] found that medical students with a depth-perception defect performed worse on a basic laparoscopic task. Initial learning occurred with 20 minutes of training; however, the performance gap remained constant between these students and those with normal depth perception. Mazyn et al.[17] found that a group with a significant lack of stereopsis did not improve with training during a catching task. However, catching a ball is not comparable to performing cataract surgery, and stereoacuity is only 1 factor that determines surgical skills.[14,15,18] Furthermore, there is great variation within the group of

Table 3. Comparison of performance parameters in men and women.

Module/Parameter	Men		Women		
	Median	Range	Median	Range	*P* Value
Cataract navigation training					
Overall score (out of 100)	9.5	0, 76	12	0, 57	.947
Time with instruments inserted (s)	336.5	118, 621	415.5	99, 623	.456
Injured cornea area value	0.52775	0, 3.17	0.5185	0, 5.59	.467
Injured lens area value	0.564	0.0179, 2.49	0.251	0.0179, 2.71	.138
Completed objects (out of 12)	11	1, 12	11	8, 12	.541
Cataract forceps training					
Overall score (out of 100)	57	0, 80	53.5	0, 94	.347
Time with instruments inserted (s)	79	43, 312	78	39, 118	.365
Injured cornea area value	0	0, 8.09	0.02775	0, 8.11	.277
Injured lens area value	0.627	0.0179, 9.41	0.7795	0.0179, 7.53	.749
Capsulorhexis					
Overall score (out of 100)	29	0, 86	3.5	0, 89	.101
Time with instruments inserted (s)	107	40, 297	119.5	53, 254	.384
Injured cornea area value	1.525	0, 12.3	1.0385	0, 6.61	.384
Injured lens area value*	—	—	—	—	–

*Too many zero events to allow statistical analysis

individuals with deficient stereoacuity, and some of them can perform on the same level as those with normal stereoacuity.[6,7,19] Further studies are therefore needed to evaluate the longitudinal effects of stereoacuity on microsurgical skills learning.

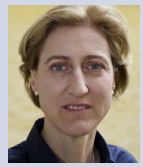
REFERENCES

1. Randleman JB, Wolfe JD, Woodward M, Lynn MJ, Cherwek DH, Srivastava SK. The resident surgeon phacoemulsification learning curve. Arch Ophthalmol 2007; 125:1215–1219. Available at: http://archopht.ama-assn.org/cgi/reprint/125/9/1215. Accessed July 15, 2011
2. Binenbaum G, Volpe NJ. Ophthalmology resident surgical competency; a national survey. Ophthalmology 2006; 113: 1237–1244
3. Wong NWK, Stokes J, Foss AJW, McGraw PV. Should there be a visual standard for ophthalmologists and other surgeons? Postgrad Med J 2010; 86:354–358
4. Suleman R, Yang T, Paige J, Chauvin S, Alleyn J, Brewer M, Johnson SI, Hoxsey RJ. Hand-eye dominance and depth perception effects in performance on a basic laparoscopic skills set. JSLS 2010; 14:35–40. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3021312/pdf/jsls-14-1-35.pdf. Accessed July 15, 2011
5. Melmoth DR, Finlay AL, Morgan MJ, Grant S. Grasping deficits and adaptations in adults with stereo vision losses. Invest Ophthalmol Vis Sci 2009; 50:3711–720. Available at: http://www.iovs.org/content/50/8/3711.full.pdf. Accessed July 15, 2011
6. Barry GP, Simon JW, Auringer D, Dunnican W, Zobal-Ratner J. Performance of strabismic subjects using a validated surgical training module: a pilot study. J AAPOS 2009; 13:350–353; 353e1–2
7. Sachdeva R, Traboulsi EI. Performance of patients with deficient stereoacuity on the EYESi Microsurgical Simulator. Am J Ophthalmol 2011; 151:427–433
8. Rossi JV, Verma D, Fujii GY, Lakhanpal RR, Wu SL, Humayun MS, de Juan E Jr. Virtual vitreoretinal surgical simulator as a training tool. Retina 2004; 24:231–236
9. Selvander M, Åsman P. Virtual reality cataract surgery training: learning curves and concurrent validity. Acta Ophthalmol (Oxf) 2010 Nov 5; [Epub ahead of print]
10. Feudner EM, Engel C, Neuhann IM, Petermeier K, Bartz-Schmidt KU, Szurman P. Virtual reality training improves wet-lab performance of capsulorhexis: results of a randomized, controlled study. Graefes Arch Clin Exp Ophthalmol 2009; 247:955–963
11. Privett B, Greenlee E, Rogers G, Oetting TA. Construct validity of a surgical simulator as a valid model for capsulorhexis training. J Cataract Refract Surg 2010; 36:1835–1838
12. Webber AL, Wood JM, Gole GA, Brown B. The effect of amblyopia on fine motor skills in children. Invest Ophthalmol Vis Sci 2008; 49:594–603. Available at: http://www.iovs.org/content/49/2/594.full.pdf. Accessed July 15, 2011
13. Shane MD, Pettitt BJ, Morgenthal CB, Smith CD. Should surgical novices trade their retractors for joysticks? Videogame experience decreases the time needed to acquire surgical skills. Surg Endosc 2008; 22:1294–1297
14. Kolozsvari NO, Andalib A, Kaneva P, Cao J, Vassiliou MC, Fried GM, Feldman LS. Sex is not everything: the role of gender in early performance of a fundamental laparoscopic skill. Surg Endosc 2011; 25:1037–1042
15. Enochsson L, Isaksson B, Tour R, Kjellin A, Hedman L, Wredmark T, Tsai-Felländer L. Visuospatial skills and computer game experience influence the performance of virtual endoscopy. J Gastrointest Surg 2004; 8:874–880; discussion 880
16. Dooley IJ, O'Brien PD. Subjective difficulty of each stage of phacoemulsification cataract surgery performed by basic surgical trainees. J Cataract Refract Surg 2006; 32:604–608
17. Mazyn LIN, Lenoir M, Montagne G, Delaey C, Savelsbergh GJP. Stereo vision enhances the learning of a catching skill. Exp Brain Res 2007; 179:723–726

18. Grantcharov TP, Bardram L, Funch-Jensen P, Rosenberg J. Impact of hand dominance, gender, and experience with computer games on performance in virtual reality laparoscopy. Surg Endosc 2003; 17:1082–1085
19. Murdoch JR, McGhee CNJ, Glover V. The relationship between stereopsis and fine manual dexterity: pilot study of a new instrument [letter]. Eye 1991; 5:642–643

OTHER CITED MATERIAL

A. Elliot A. Is stereopsis essential to be a competent ophthalmic surgeon? A literature review. The Royal College of Ophthalmologists - Visual Standards Sub-committee, 2008. Available at: http://www.rcophth.ac.uk/core/core_picker/download.asp?id=351. Accessed July 15, 2011



First author:
Madeleine Selvander, MD

Department of Clinical Sciences, Lund University, Malmö, Sweden