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Simulation models in direct ophthalmoscopy education: a systematic review

Modèles de simulation dans l'enseignement de l'ophtalmoscopie directe : revue systématique

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Abstract

Background: An ever-increasing range of simulation devices are available for direct ophthalmoscopy. However, the effectiveness of simulation design and components have not been evaluated. This systematic review aims to describe and evaluate direct ophthalmoscopy simulation models and highlight components that have been found to be effective, and challenges faced when using simulation models.

Methods: A systematic review of the literature was conducted according to the PRISMA statement in four online databases: Medline, Embase, Cochrane Library and Web of Science. Citation searching using Google Scholar and Citationchaser was also undertaken. Validity and effectiveness were assessed using a validated scale based on Messick's modern validity framework and McGaghie's proposed levels of simulation-based translational outcomes respectively.

Results: A total of 1,275 titles and abstracts were screened. A total of 37 studies were included in the final analysis. Physical models, digital models and virtual reality direct ophthalmoscopy models were described in studies. A plastic cannister design was the most common in the literature, followed by a sphere with a painted fundus and the EyeSi Direct Ophthalmoscope Simulator (VRmagic, GmbH, Mannheim, Germany). Simulation was effective in its ability to allow students to engage in repeated practice without patient discomfort. The lack of realism was the most noted limitation of simulation practice.

Conclusion: While more robust evidence is needed to support simulation design efficacy in direct ophthalmoscopy, simulation-based teaching of direct ophthalmoscopy will likely be increasingly effective as technological advancements support improved realism and affordability.

Résumé

Contexte : Il existe une gamme toujours plus large de dispositifs de simulation pour l'ophtalmoscopie directe. Cependant, l'efficacité de la conception et des composants des simulations n'a pas été évaluée. Cette revue systématique vise à décrire et à évaluer les modèles de simulation d'ophtalmoscopie directe, à mettre en évidence les composants qui se sont révélés efficaces et à souligner les défis rencontrés lors de l'utilisation de modèles de simulation.

Méthodes : Une revue systématique de la littérature a été réalisée conformément à la déclaration PRISMA dans quatre bases de données en ligne : Medline, Embase, Cochrane Library et Web of Science. Une recherche de citations à l'aide de Google Scholar et Citationchaser a également été effectuée. La validité et l'efficacité ont été évaluées à l'aide d'une échelle validée basée respectivement sur le cadre de validité moderne de Messick et les niveaux proposés par McGaghie pour les résultats translationnels basés sur la simulation.

Résultats : Au total, 1 275 titres et résumés ont été examinés. Au total, 37 études ont été incluses dans l'analyse finale. Les études décrivaient des modèles physiques, des modèles numériques et des modèles d'ophtalmoscopie directe en réalité virtuelle. La conception d'un boîtier en plastique était la plus courante dans la littérature, suivie d'une sphère avec un fond peint et du simulateur d'ophtalmoscope direct EyeSi (VRmagic, GmbH, Mannheim, Allemagne). La simulation s'est avérée efficace pour permettre aux étudiants de s'exercer de manière répétée sans causer de gêne aux patients. Le manque de réalisme était la limite la plus souvent mentionnée de la pratique de la simulation.

Conclusion : Bien que des preuves plus solides soient nécessaires pour étayer l'efficacité de la conception de la simulation en ophtalmoscopie directe, l'enseignement de l'ophtalmoscopie directe basé sur la simulation sera probablement de plus en plus efficace à mesure que les progrès technologiques permettront d'améliorer le réalisme et l'accessibilité financière.

Introduction

Direct ophthalmoscopy (DO) remains an essential basic skill in medical education. For non-specialists, it can play a crucial role in diagnosing ophthalmic disease, which may constitute 2-19% of patient presentations to general practioners and hospital emergency departments.[1-3] DO also allows for rapid screening and assessment of systemic disease, which may prompt essential sight-saving or life-saving therapy.[4]

However, proficiency of medical practitioners in performing DO has been poor.[5-9] This may be due to a lack of regular practice,[10,11] which is exacerbated by the reduction in ophthalmology teaching time in medical schools in countries such as Australia,[2,12] Canada,[13] UK,[14,15] and USA.[16] This undoubtedly contributes to a lack of confidence in performing DO, reducing its use by medical students and doctors in clinics and hospitals.[8,17-19]

The evident mismatch between the utility of DO and its current use in clinical practice has encouraged investigation into methods of improvement in DO education. This has resulted in the implementation of teaching practices such as modified teaching ophthalmoscopes,[20] non-mydriatic fundus cameras[21] and fundus photograph matching.[22,23] A practice that has proved to be particularly promising is the use of simulation in DO education. Simulation allows for repeated convenient practice of DO technique, as it eliminates the need for patients or patient-actors.[24,25] The use of simulation in DO education ranges from digital simulation machines[26,27] to plastic cannister eye models.[28,29]

Studies have examined the use of different models for their use in DO education.[30,31] However, a systematic review of the literature describing and evaluating simulation models for DO education is lacking. The aim of this systematic review was to describe and evaluate model designs, components and considerations that have been found to be effective, and challenges faced when using simulation models to teach and assess direct ophthalmoscopy.

Methods

This systematic review was conducted according to the PRISMA statement. The review was registered on an international prospective register of systematic reviews (PROSPERO) prior to carrying out literature searches (registration ID: CRD42023437488).

Search methods

A comprehensive literature search was conducted in July 2023 in four online databases: Medline, Embase, Cochrane Library and Web of Science. To identify additional citations, searching in Google Scholar and citation searching via Citationchaser was also undertaken. A combination of free-text and thesaurus searching was used. No search limit was applied.

Inclusion and exclusion criteria

Inclusion and exclusion criteria were based on a population, intervention, comparison and outcome strategy. For studies to be included, participants could be medical students, medical practitioners, allied health staff and other health science students. Interventions that were preferred included training on a given simulation model. Simulation models include any device that served as an artificial eye, or that provided students with examination findings that mimicked those found in DO. Studies were included regardless of the model of ophthalmoscope used. Studies were also included if they described new simulation models and lacked experimental design. Outcomes that were preferred included academic grades or proficiency and measures of confidence and preference. Studies were included which included either qualitative or quantitative outcomes of eye model utility for DO. Studies that described model eyes designed for uses other than direct ophthalmoscopy, such as indirect ophthalmoscopy training and surgical training, were excluded from the paper.

Data collection

Titles and abstracts of all studies returned from the literature search were screened independently by the first and second author. Studies that were thought to meet the eligibility criteria had full texts screened by the first and second author. Disagreements were resolved by discussion.

The first and second author independently extracted data from full texts of studies that met the eligibility criteria. Data collected included author details, year of publication, title of study, country that the study was run, participants, study design, methodology, outcome, ophthalmoscopy simulator details, role of simulation model, study conclusions, benefits and drawback of using simulation in ophthalmoscopy, and benefits and drawbacks of the particular simulation model used in the study.

Data analysis

Studies were arranged according to the type of simulator used: physical, digital, augmented reality, and/or virtual reality. Validity of each study was assessed using a validated scale developed by Beckman, Cook and Mandrekar[32] based on Messick's modern validity framework in Table 1.[33] This scale assesses validity based on the parameters of content, response processes, internal structure, relations to other variables and consequences. Each parameter is rated on the following scale: NA (no discussion of source of validity evidence), 0 (discussion of source of validity but no data presented), 1 (data weakly supports source of validity or is limited) and 2 (data strongly supports source of validity). The effectiveness of each simulator design was evaluated based on McGaghie's proposed levels of simulation-based translational outcomes adapted to the outcomes of this study in Table 2.[34] Each study was also assessed using the Kirkpatrick's Model for Training Outcomes.[35,36] This is a 4-level model that evaluates training programs based on their impact on participants and is summarised in Table 3.[35,36]

Table 1. Validity assessment scale based on Messick's modern validity framework[32,33]

Parameter	Definition	Example
Content	Effectiveness of test items in measuring a desired construct, referring to its format, themes and wording	Expert review of a test to ensure items are representative of all aspects the construct being measured
Response processes	Analysis of thought processes and behaviours of participants and observers, with reference to the intended construct.	Standard setting of test administration, interviews of participants to understand reasons behind their responses.
Internal structure	The reliability of test items to assess a construct. Complex constructs may require test items to be multidimensional, whereas simple constructs my require homogenous test items.	Calculating factor analysis, inter-term reliability and test-retest reliability
Relations to other variables	Relationship between test scores and external measures that have theoretical relevance	Comparing test scores with those of different expertise, or in a different clinical setting or speciality.
Consequences	Desired and unintended impacts of using the test	Comparing test scores on a simulation device with patient satisfaction, or ease of use of DO in a clinical setting.

Table 2. Effectiveness assessment scale based on McGaghie et al.[34] proposed levels of simulation-based translational outcomes

Parameter	Definition	Example	Rating
Internal acceptability	Trainee/student satisfaction with simulator	Interviewing students on usability of simulators	Level 1
Contained effects	Changes in performance in using the simulator	Post training assessment of performance using a DO simulator	Level 2
Downstream effects	Changes in behaviour in clinical setting	Performance of students doing DO with real patients	Level 3
Target effects	Changes in patient outcomes	Assessing accuracy of diagnosis and/or changes in patient morbidity and mortality	Level 4
Collateral effects	Changes on a hospital-wide or systems level	Skill retention, rates of misdiagnosis, economic effects	Level 5

Table 3. Kirkpatrick Model for training outcomes

Parameter	Definition	Example	Rating
Reaction	Evaluation of a training program that gauges motivation, interest and attention of participants.	Post-course satisfaction survey	Level 1
Learning	Evaluation of a training program that gauges knowledge acquisition of a participant	Written assessments, quizzes or OSCEs	Level 2
Behaviour	Evaluation of a training program based on participants ability to use their skills in the workplace	Ward based assessments, supervisor reports	Level 3
Results	Evaluation of a training program based on its overall impact, usually on system wide outcomes.	System wide audits on patient outcomes or finances	Level 4

Results

The screening process is summarised in Figure 1, with a total of 1,263 titles and abstracts screened. A total of 37 studies were included in the final analysis. There was strong inter-rater reliability between authors (Cohen's Kappa = 0.8344).

A summary of the demographics of included studies are presented in Table 4. A more detailed demographics table, including citations to relevant studies, is presented in Supplementary Table 1. Details of each included study are summarised in Appendix A, including measures of validity and simulator effectiveness. Most included studies displayed poor measures of validity. Studies also showed poor effectiveness ratings for their respective simulation technique. Only one study achieved a Kirkpatrick Level 3, while 20 (54%) studies achieved a Level 2 and 8 (22%) studies achieved a Level 1.

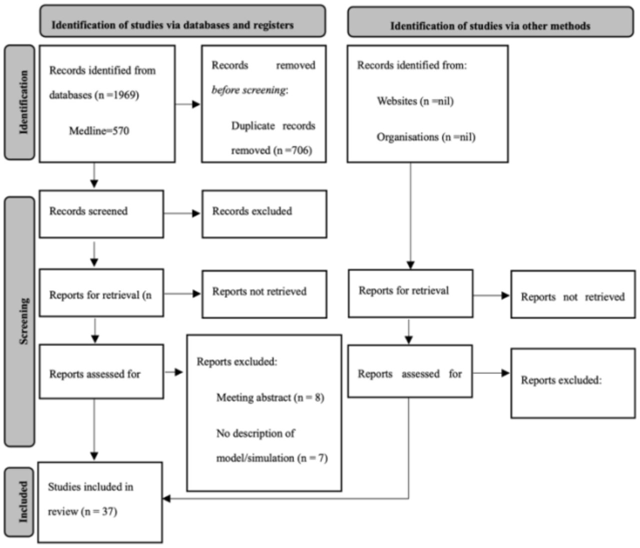

Figure 1. PRISMA diagram of study selection

There were a variety of ophthalmoscopy simulator models used in included studies, some of which are commercially available. The most common commercially available models used in studies include the EyeSi Direct Ophthalmoscope Simulator (VRmagic, GmbH, Mannheim, Germany)[37,38,39,40,41] (*n* = 5, 14%), Eye Examination Simulator (Kyoto Kagaku Co. Ltd., Kyoto, Japan)[26,42,43,44] (*n* = 4, 11%) and Eye Retinopathy Trainer (Adam, Rouilly, Sittingbourne, Kent, UK)[27,45,46] (*n* = 3, 18%).

The most widely reported benefit of simulation models for direct ophthalmoscopy teaching is that students are allowed repeated practice without causing discomfort to patients.[27,38,40,41,43,47,48,49,50] Students who underwent direct ophthalmoscopy training using simulation models were also more capable of performing DO on initial contact with patients.[38,40] Additionally, students were more confident when interacting with patients after training on DO simulation models.[44,49] A simulation environment was perceived by students as low pressure and hence increased their positive experience of acquiring a difficult skill.[44,48]

The most commonly cited challenge of simulation models for DO include the lack of realism.[40,41,43] The simulation environment was felt to be not as true to the clinical scenario as it would be if students practiced on simulated patients.[40,41,43]

Table 4. Demographic data with reference to included studies

Features	Number (%)
Year	
Before 2000	6 (16%)
2000-2009	5 (14%)
2010-2019	17 (46%)
2020-2023	9 (24%)
Number of participants	
NA	9 (24%)
1-100	15 (55%)
101-200	6 (16%)
More than 200	2 (5%)
Type of participants	
Medical students	22 (59%)
Non-medical students	2 (5%)
Junior doctors	4 (11%)
Senior doctors / consultants	1 (3%)
University staff	1 (3%)
Country	
Australia	2 (5%)
Brazil	2 (5%)
Canada	5 (14%)
China	1 (3%)
Colombia	1 (3%)
Denmark	1 (3%)
Germany	2 (5%)
Japan	1 (3%)
Saudia Arabia	1 (3%)
South Africa	1 (3%)
Tunisia	1 (3%)
UK	5 (14%)
USA	14 (38%)
Type of simulator	
3D printed model	2 (5%)
Ball with painted fundus	5 (14%)
Eye Examination Simulator (Kyoto Kagaku Co. Ltd., Kyoto, Japan)	4 (11%)
Eye Retinopathy Trainer (Adam, Rouilly, Sittingbourne, Kent, UK)	3 (8%)
EyeSi Direct Ophthalmoscope Simulator (VRmagic, GmbH, Mannheim, Germany)	5 (14%)
Iowa Ophthalmoscopy Model	1 (3%)
Mannequin head	3 (8%)
OphthoSim	1 (3%)
Plastic cannister	8 (22%)
Timberlake Eye Model	1 (3%)
VR or AR Headset	5 (14%)

Physical simulation models

Plastic cannister models were the most common type of simulator used (*n* = 8, 22%). The basic design of this involves a cylindrical cannister with an aperture on one end, with fundus slides on the other end. Some cannister models feature variable axial lengths and contact lenses to simulate hyperopia or myopia. Swanson et al.[51] administered a pre-test and post-test after students trained on four types of plastic cannister DO simulation models. They found students had improved confidence levels and knowledge of pathology after training on plastic cannister models. Chung et al.,[52] Donovan et al.,[53] and Levy[54] agreed that a plastic cannister design was cost-effective, easy to set up with readily available materials and could easily display both normal and pathologic fundi with interchangeable slides. Another benefit noted in the study by Kelly et al.[48] was the ability for cannister models to simulate the optics of real eyes with the addition of a contact lens. Wessels et al.[55] noted that changing the axial length of cannister models can simulate a range of ametropia, thereby changing the difficulty for students. Kennedy et al.[56] described the Timberlake Eye Model, a commercially available plastic cannister design with a variable axial length and ability to display fundus photos with pathology. The benefits of this design included the lower cost, and ability to vary simulation difficulty. A draw back of the Timberlake Eye model is the low quality of fundus photos. Another drawback of the cannister design is that students must maintain a fixed orientation with respect to the cannister during examination, or else the fundus view will be lost.[52,53]

Other common physical simulator designs include spherical models, that can be made with either a tennis ball or ping-pong ball, with an aperture opposite a fundus. Fundus features were either represented with photos or were painted to the inside surface of the sphere. Martins et al.[49] assessed students' ability to perform DO with simulation training compared to without simulation training, using an eye model with a plastic sphere design. Here, pupil size and ametropia could be simulated, altering the difficulty of the simulated exam. Since the component materials are readily available, the cost effectiveness of this design has been emphasised.[35,57]

Two studies used 3D printing to produce simulation models for DO training. This method was also cost effective. Khan and Hennessy[58] described the Prince of Wales Eye Model with an area for insertable lenses and an option for inserting a cartridge with normal or pathologic fundus images, which also allows different difficulty of simulation. However, only a 35mm diameter lenses can be used, and examination of the peripheral pole of the retina requires a separate lens which adds cost. Wu et al.[50] conducted a randomised control trial where students trained on either simulated patients and an eye model, or only on a simulated patient using a 3D printed eye model, and found that training with an eye model improved fundus identification rate and time. Benefits of this design included fewer components, simple assembly, a realistic curved posterior pole and ability to change fundus photos.

Four studies included the use of the Eye Examination Simulator (Kyoto Kagaku Co. Ltd., Kyoto, Japan), a commercially available simulation model that is comprised of a mannequin head with an adjustable pupil size and interchangeable fundus slides that can display different retinal conditions. Larsen et al.[44] found students who practiced on this model increased their confidence and DO ability. However McCarthy et al.[26] noted that students still felt that that this simulation method was not realistic and image quality was poor. This was echoed in a study by Bukhari,[43] where participant noted that the model does not simulate a real time clinical scenario compared to practicing on patients.

Digital simulation models

The only digital simulation model used in studies was the Eye Retinopathy Trainer (Adam, Rouilly, Sittingbourne, Kent, UK). This design involves a mannequin head with a high-resolution digital screen display on the fundus. This can display diabetic, common and less common retinal conditions. This model was used in three studies. Gupta et al.[45] and Yusuf et al.[46] noted increased confidence and comfort when students trained on this simulation model. However, the cost, lack of physician-patient relationship and need for trained teaching staff have been cited as potential drawbacks by Androwiki et al.[27]

Virtual and Augmented reality simulation models

The most common virtual reality DO simulator used in studies was the EyeSi Direct Ophthalmoscope Simulator (VRmagic, GmbH, Mannheim, Germany). The EyeSi DO simulator consists of an ophthalmoscope handpiece with a built-in digital screen display and a patient model head connected to an external touchscreen display. Patient cases and pathologies are programmed into the device, and objective feedback is provided to students based on their performance. Boden et al.[38] evaluated the use of the EyeSi DO simulator in an OSCE setting. Students found that the model had high realism with its ability to imitate eye movements, blinking and pupil size. Both Boden et al.[38] and Howell et al.[40] noted the potential for real-time instructor feedback with the use of the additional monitor on EyeSi. This feature also allows the EyeSi to be used effectively in exam scenarios as the examiner can see what the student is assessing.[54] DO EyeSi Deuchler et al.[39] conducted a pre-test and post-test on students after training with EyeSi Direct or with a combination of EyeSi direct and EyeSiNet for direct and indirect ophthalmoscopy and found that learning is observed with simulator training, but is higher if students trained on both a simulator and theory based online platform. Tso et al.[41] allowed students to complete a traditional DO teaching session followed by EyeSi DO simulator, and surveyed student's confidence in DO. Training on the EyeSi improved students' confidence and was preferred by the majority of students compared to traditional DO teaching methods. Additional benefits noted were the ability for real-time labelling of fundus pathology, and the variable difficulty levels, with easier starting points for beginners. Students did find that the online modules were lengthy, and some expressed a preference for more normal fundi to examine. Howell et al.[40] describes that one of the major challenges faced when student train on the EyeSi includes the persisting unfamiliarity with the operation of an actual direct ophthalmoscope.

Other VR DO simulation solutions involve programming a DO simulation software to existing VR headsets and were used by five studies. Beneficial features of these models include the ability to display fundus pathologies. Wilson et al.[59] carried out a user evaluation after completing a training module on a VR headset with gamified training module that outlines eye anatomy and DO steps. Whilst participants did increase in confidence in performing DO, they felt that the simulation design was not realistic, as there was a lack of a physical mannequin head to manoeuvre around. Acosta et al.[60] highlights that software developments are needed to increase the effectiveness of these VR simulations. Chan et al.[61] compared the use of the HTC Vive controller-based examination, Valve Index "Knuckle" controller-based examination, Microsoft HoloLens gesture-based examination, and noted that participants found it difficult to familiarise with operation of the three different simulations, and that headsets were heavy, and voice commands were inaccurate.

Discussion

Direct ophthalmoscopy simulation models utilise a range of technologies to provide increasingly effective learning opportunities to students. The studies in this systematic review highlight key benefits and challenges faced in direct ophthalmoscopy simulation in medical education. An important benefit of simulation training is to provide students with a safe environment to have repeated practice without potential inconvenience or harm to real patients.[27,38,40,41,43,47,48,49,50] This benefit has been shown in simulation training in other medical disciplines such as general surgery, obstetrics and anaestheics.[62,63] Repeated practice has been shown to be beneficial in the cognitive and metacognitive aspects of learning.[64-66]

The increase in confidence of participants is an important and often overlooked benefit of simulation design.[41,44,46,49] Confidence and perceived competence can increase students' autonomous motivation, which has been shown to improve learning outcomes.[67] An increase in student confidence may allow students to be more involved in their clinical placements and hence has the potential to increase their exposure to real patient scenarios. DO simulation may therefore provide a suitable adjunct to training on simulated patients.

A recent systematic review by Paik et al.[68] looked at technology-enhanced methods for direct ophthalmoscopy training, including smartphone ophthalmoscopy, tracked and non-tracked direct ophthalmoscopy simulation models (where tracked models had a real-time projection of the learner's view). Paik et al.[68] had also found improved efficacy of simulation models in direct ophthalmoscopy training, where non-tracked direct ophthalmoscopy simulators and smartphone ophthalmoscopy were superior in training competency relative to control traditional direct ophthalmoscopy on real eyes. However, studies using tracked direct ophthalmoscopy training showed non-superiority compared to controls, which was attributed to possible effect of minimal instructor guidance in these training programs. Paik et al.[68] had also found an increase in participants confidence and perceived competence in DO after training on simulation models. With this, simulation models were shown to be important tools in direct ophthalmoscopy training, which is similar to the findings of our review.

Smartphone ophthalmoscopy was excluded from this systematic review, as it is not currently approved in use in healthcare settings. However, smartphone ophthalmoscopy may pose some benefits over traditional ophthalmoscopy as outlined by Paik et al.,[68] including a more gradual learning curve, the ability to capture images, diagnostic accuracy, clinical competence and confidence. There is also possibility for future integration of AI models in recognising clinical signs in screening and diagnosis. Hence its use should be assessed and validated in healthcare settings, as it is an important consideration for the future direction of ophthalmoscopy.

Future developments in direct ophthalmoscopy simulation models should address the challenges outlined in this systematic review. Firstly, most of the studies that qualified for this review were of Kirkpatrick level 1 or 2, and did not examine effectiveness in the clinical context, or its impact on the wider health system. Studies looked only at student satisfaction or improvements in simulation performance. Studies on simulation in medical specialties other than ophthalmology also often show improvement in theoretical and clinical knowledge and procedural skills, however the majority of these studies do not report impact on clinical outcomes.[62,69] Additionally, eight studies presented were descriptive studies, and 15 studies were a prospective single arm design with no control group. While these studies are important initial steps, a stronger evidence base should be built to support direct ophthalmoscopy simulation training and further investigate its effective components.

Secondly, it is important to ensure that simulation models enact a high level of realism. In this context, realism refers to not only the physical resemblance of a simulation model to its human counterpart, but also how a simulation exercise unfolds, and how the simulation interacts to its surrounding environment.[70] In direct ophthalmoscopy, this may involve the use of mannequin heads, or a spherical eyeball model, which may allow students to practice the manoeuvring involved in performing this examination in the clinical environment.

Thirdly, it is important to note that cost of simulation has a significant impact on the opportunity to access to these devices. Low cost of production was highlighted in many studies in this review.[27,48,50,52,53,56,71] Nevertheless, some of these models may still not be affordable in certain educational circumstances, such as in lower income societies where DO is nevertheless a required clinical skill. Hence it may be important for newer simulation devices to attempt to limit their cost to consumers with measures that do not compromise the effectiveness of simulation, such as by providing lower fidelity mannequins.[72] Newer technologies such as 3D printing may address this, as it allows for the development of cost effective of models.[50,58]

Conclusion

The developments in simulation models for direct ophthalmoscopy have proven to be effective in improving student satisfaction and learning outcomes. This systematic review highlights effective components of certain simulation designs. Future developments in direct ophthalmoscopy simulation may include improving realism and addressing affordability. Although more robust evidence is needed on simulation design efficacy in direct ophthalmoscopy, we have already seen a promising rise in the use of simulation based medical education as an adjunct to traditional teaching methods. With the continuous advances in fidelity and affordability in technology, it appears undeniable that simulation will play an ever-increasing role in ophthalmology education.

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Appendix A. Summary of included studies

Reference	Participants	Study Design	Outcome	Simulator	Role of simulation model	Conclusion	Validity	Effectiveness	Kirkpatrick level
Physical									
Akaishi[42]	73 medical students, residents and physicians	Prospective single arm cross-sectional study	Surrogate indicators of experience and ability to identify words at the fundus	Eye Examination Simulator (Kyoto Kagaku Co. Ltd., Kyoto, Japan)	Assessment of identification of fundoscopic pathology	Can be used to in assessment to differentiate performers when pupil size is between 2-3.5mm	Content: N Response process: 0 Internal structure: N Relations to other variables: N Consequences: N	NA	Level 2
Bradley[71]	395 medical students	Prospective single arm cross-sectional study	OSCE Exam scores initially and after 6 months	Tennis ball. Disc, macula, vessels and words painted on the inside	Training students to identify fundus characteristics	Model can be used to assess effectiveness of DO technique	Content: N Response process: 0 Internal structure: N Relations to other variables: N Consequences: N	2	Level 2
Bukhari[43]	14 medical students	Prospective single arm cross-sectional study	Cognitive and motor skills at DO and ability to diagnose DR in an OSCE scenario	Eye Examination Simulator (Kyoto Kagaku Co. Ltd., Kyoto, Japan)	Training students to identify fundus pathology	Training on a simulator significantly improved cognitive, motor and diagnostic skills using DO	Content: N Response process: 0 Internal structure: N Relations to other variables: N Consequences: N	2	Level 2
Chung et al.[52]	NA	Device description	NA	Plastic cannister (single lumen)	Training students to identify fundus pathology	A simple device, easy to set up and use	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: 1	1	NA
Dodaro et al.[47]	NA	Device description	NA	Mannequin head, model eyes with printed fundi	Training students to identify fundus pathology	Should provide a valuable teaching tool in the clinical setting	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	NA	NA
Donovan et al.[53]	NA	Device description	NA	Plastic cannister (single modifiable lumen)	Training students to identify fundus pathology	A cost-effective simulator that can simulate fundus pathologies and simulate anterior segment conditions	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	NA	NA
Kahlenborn et al.[73]	USA	Device description	NA	Mannequin head with interchangeable fundus slides	Training students to identify fundus pathology	Effective simulation of fundus and clinician-patient relationship	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	NA	NA
Kelly et al.[48]	119 medical students	Randomised control trial	Post-test on normal and abnormal fundus	Plastic cannister with fundus photos	Training students to identify fundus pathology	Students prefer fundus photos and human	Content: 0 Response process: 0 Internal structure: 0	3	Level 2

Reference	Participants	Study Design	Outcome	Simulator	Role of simulation model	Conclusion	Validity	Effectiveness	Kirkpatrick level
			features, and student preferences	and a 16D convex lens		volunteers over simulators for training	Relations to other variables: 0 Consequences: N		
Kennedy et al.[56]	8 clinician educators	Prospective single arm cross-sectional study	Focus group evaluation of new model	Timberlake Eye Model	Training students to identify fundus pathology	The Timberlake Eye Model was deemed practical, useful and cost effective	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	1	Level 1
Khan and Hennessy[58]	NA	Device description	NA	Prince of Wales Eye Model	Training students to identify fundus pathology	3D printed model with area for insertable lens with option for inserting a cartridge with fundus images	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	NA	NA
Larsen et al.[44]	245 medical students	Prospective single arm cross-sectional study	Self-administered theoretical pretest and post-test scores on student perceptions	Eye Examination Simulator (Kyoto Kagaku Co. Ltd., Kyoto, Japan)	Training students to identify fundus pathology	Simulation improves skill and confidence in DO, which can be applied in clinical practice	Content: N Response process: N Internal structure: N Relations to other variables: 0 Consequences: 0	3	Level 2
Levy[54]	133 medical students	Prospective single arm cross-sectional study	OSCE scores and survey result	Table tennis ball, with lens and painted fundus in a mannequin head	Assessment of identification of fundoscopic pathology	Model was used effectively in the OSCE scenario	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	2	Level 2
Mackay et al.[74]	107 medical students	Randomised control trial	Post-test on normal and abnormal fundus features, and student preferences	Plastic cannister with fundus photos and a 16D convex lens	Evaluating correct identification of pathology	Students prefer fundus photos over DO for detecting disorders	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	2	Level 2
Mahmoud et al.[75]	48 medical students	Prospective single arm cross-sectional study	Post-test MCQ scores and student preferences	Plastic cannister in model head with exchangeable fundi and modifiable pupils	Training students to identify fundus pathology	Simulation training can improve skills and knowledge of DO	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	2	Level 2
Martins et al.[49]	30 medical students	Prospective single arm cross-sectional study	Identify pathologies in patients	Plastic sphere in a cardboard box	Training students to identify fundus pathology	Simulation was an effective way to practice and gain confidence. Increasing difficulty during the simulation process was beneficial. Students felt safer when performing DO on patients	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	3	Level 3

Reference	Participants	Study Design	Outcome	Simulator	Role of simulation model	Conclusion	Validity	Effectiveness	Kirkpatrick level
McCarthy et al.[26]	43 resident medical officers	Prospective single arm cross-sectional study	Quantifiable assessment of fundoscopic skills and ease of use of the model	Eye Examination Simulator (Kyoto Kagaku Co. Ltd., Kyoto, Japan)	Assessment of identification of fundoscopic pathology	May be suitable for training and assessment, but has lower user satisfaction	Content: N Response process: 0 Internal structure: N Relations to other variables: N Consequences: N	NA	Level 2
Miller[76]	NA	Device description	NA	Jar with pupil aperture and fundus pictures	Training students to identify fundus pathology	Students appreciated practice on a simulation device	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	1	NA
Penta et al.[77]	30 students	Randomised control trial	Post-test scores	Iowa ophthalmoscopic model, Bartner eye model	Training students to identify fundus pathology	Supplementing traditional methods with simulation can be effective in in improving students' ability to perform DO	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	1	Level 2
Swanson et al.[51]	144 medical students, 9 faculty	Prospective single arm cross-sectional study	Post-test MCQ scores and student preferences	Four variations of a plastic cannister design with different pupil aperture sizes	Training students to identify fundus pathology	Simulator was a useful adjunct, well received by students, and improved post-test scores of OD proficiency	Content: N Response process: N Internal structure: N Relations to other variables: 1 Consequences: N	2	Level 2
van Velden[78]	173 medical students	Prospective single arm cross-sectional study	Ability to visualise the fundus and make a correct diagnosis	Mannequin head with model eyes with artificial corneas and printed fundi	Assessment of identification of fundoscopic pathology	Model was used effectively in the OSCE scenario, students needed more DO teaching in pathological conditions	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	1	Level 2
Wang et al.[57]	76 ophthalmology residents	Prospective single arm cross-over study	Checklist score and objective assessment of DO	Plastic ball with convex lens and painted fundus	Assessment of identification of fundoscopic pathology	The majority of students were agreeable to using the simulation model. The model can be used in assessment and can differentiate between performers	Content: N Response process: 2 Internal structure: N Relations to other variables: N Consequences: 2	2	Level 2
Wessels et al.[55]	NA	Device description	NA	Camera film case with variable axial length and refractive properties	Training students to identify fundus pathology	May be suitable for training and assessment	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	NA	NA
Wu et al.[50]	92 medical students	Randomised control trial	Assessment of ability and time taken to visualise the fundus	3D-printed rectangular models with apertures and replaceable fundus photographs	Training students to identify the fundus	Training with an eye model improved fundus identification rate and time	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	3	Level 2

Reference	Participants	Study Design	Outcome	Simulator	Role of simulation model	Conclusion	Validity	Effectiveness	Kirkpatrick level
Digital									
Androwiki et al.[27]	90 medical students	Randomised control trial	Theory and practical exam scores	Eye Retinopathy Trainer (Adam Rouilly)	Training students to identify fundus characteristics	Simulation group performed statisticaly better than control group	Content: N Response process: 0 Internal structure: N Relations to other variables: N Consequences: N	3	Level 2
Gupta et al.[45]	48 neurology residents	Randomised control trial	Pretest and post-test scores	Eye Retinopathy Trainer (Adam Rouilly),	Training students to identify fundus pathology	Increase in skills score and comfort levels with DO, with no increase in knowledge, frequency of attempting DO or perceptions of usefulness of DO	Content: 0 Response process: 1 Internal structure: 0 Relations to other variables: N Consequences: N	2	Level 2
Kouzmitcheva et al.[27]	17 paediatric residents	Randomised control trial	Post-test on normal and abnormal fundus features, and resident preferences	OphthoSim (OtoSim)	Training students to identify fundus pathology	Simulation improved detection of fundus pathologies compared to control	Content: N Response process: N Internal structure: 0 Relations to other variables: N Consequences: N	1	Level 2
Yusuf et al.[46]	160 medical students	Randomised control crossover trial	Student perception of educational intervention	Eye Retinopathy Trainer (Adam Rouilly)	Training students to identify the fundus	Retinal simulation together with a peer assessed OSCE is an effective at increasing confidence in students	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	1	Level 1
Virtual reality									
Boden et al.[38]	34 medical students	Randomised control trial	OSCE Exam scores	EyeSi Direct Ophthalmoscope Simulator (VRmagic, GmbH, Mannheim, Germany)	Training students to identify fundus pathology	Simulation group had statistically higher OSCE scores than the control group, and high satisfaction of students in the simulator group	Content: 0 Response process: N Internal structure: N Relations to other variables: 1 Consequences: 0	2	Level 2
Borgersen et al.[37]	13 medical students, 8 ophthalmology consultants	Prospective Validity Study	Validity evidence of a direct ophthalmoscope virtual reality simulator	EyeSi Direct Ophthalmoscope Simulator (VRmagic, GmbH, Mannheim, Germany)	Assessing DO competency in students and consultants	Pass/fail score of 2615 in EyeSi Modules, high internal validity	Content: 1 Response process: 2 Internal structure: 2 Relations to other variables: 2 Consequences: 1	NA	NA
Deuchler et al.[39]	86 medical students	Randomised control trial	Pretest and post-test scores	EyeSi Direct Ophthalmoscope Simulator (VRmagic, GmbH, Mannheim, Germany)	Training students to identify fundus pathology	Learning effect is observed with simulator training, but is higher if students train on both a simulator and theory based online platform	Content: 0 Response process: N Internal structure: 0 Relations to other variables: 0 Consequences: 2	2	Level 2
Howell et al.[40]	33 medical students	Randomised control trial	Assessment on technique and efficacy on human patients	EyeSi Direct Ophthalmoscope Simulator (VRmagic, GmbH, Mannheim, Germany)	Training students to identify fundus pathology	Increased in time spent training and skills scores in simulator group, no statistical difference in knowledge scores.	Content: 0 Response process: 0 Internal structure: 0 Relations to other	3	Level 2

Reference	Participants	Study Design	Outcome	Simulator	Role of simulation model	Conclusion	Validity	Effectiveness	Kirkpatrick level
							variables: 1 Consequences: N		
Nguyen et al.[79]	NA	Preliminary usability study	System usability scale scores	HTC Vive	Training students to identify fundus pathology	Simulator was usable but requires improvements	Content: N Response process: 2 Internal structure: 0 Relations to other variables: N Consequences: N	1	Level 1
Tso et al.[41]	31 students	Prospective single arm cross-over study	Survey responses	EyeSi Direct Ophthalmoscope Simulator (VRmagic, GmbH, Mannheim, Germany)	Training students to identify fundus pathology	EyeSi improved students' confidence and was preferred by the majority of students compared to traditional DO teaching methods	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	1	Level 1
Wilson et al.[59]	15 medical students	Model evaluation and usability study	Davis's Technological Acceptance Model score, usefulness and ease of use	VR headset with gamified training module outlining eye anatomy and DO steps	Training students to identify fundus pathology	VR simulator was perceived to increase understanding of ophthalmoscopy and was relatively easy to use.	Content: N Response process: 0 Internal structure: N Relations to other variables: N Consequences: N	1	Level 1
Augmented reality and Virtual reality									
Acosta et al.[60]	NA	Preliminary usability study	System Usability Scale (SUS)	Unnamed AR simulator and a VR simulator	Training students to identify fundus pathology	Simulator was usable, more useable with a physical fundoscopy simulator, but less useable than the EyeSi	Content: N Response process: N Internal structure: N Relations to other variables: N Consequences: N	NA	Level 1
Chan et al.[61]	10 non-medical students	Prospective single arm cross-sectional study	Ease of use and cognitive load	HTC Vive controller-based examination, Valve Index "Knuckle" controller-based examination, Microsoft HoloLens gesture-based examination	Feasibility study	Simulation models with a physical controller allows has a higher ease of use and lower cognitive load than hand tracking gestures (limited to pinching)	Content: 1 Response process: 1 Internal structure: N Relations to other variables: N Consequences: 2	2	Level 1
Chan et al.[80]	18 non-medical students	Prospective single arm cross-sectional study	Usability, task difficulty and workload	HTC Vive controller-based examination, Valve Index "Knuckle" controller-based examination, Microsoft HoloLens gesture-based examination, Oculus Quest controller and Oculus Quest hand-tracking system	Feasibility study	Simulation models with a physical controller allows has a higher ease of use while the Oculus Quest's more accurate hand motion capture result in higher usability resulted in higher usability when compared	Content: 0 Response process: 1 Internal structure: N Relations to other variables: N Consequences: 0	2	Level 1