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# Skills assessment after a grape-based microsurgical course for ophthalmology residents: randomised controlled trial

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## ABSTRACT

**Aims** To introduce and assess a course using grapes as training models for ophthalmology residents to acquire basic microsurgical skills.

**Methods** Ophthalmology residents who were novices at microsurgery were included. Participants were randomised into a 1:1 ratio to a 4-hour training programme based on fruit models (group A) or virtual reality (VR) modulator and silicone suture pads (group B), respectively. Before and after training, questionnaires were designed to measure their self-confidence with ophthalmic operations and with their coming role as surgical assistants. After training, each participant provided their interest in further studying microsurgery and was assessed for their general competence of ophthalmic microsurgery on porcine eyes.

**Results** Eighty-three participants were included, with 42 ones in group A and 41 ones in group B. After training, participants in group A performed better in the uniformities of the suture span ( $p<0.05$ ), suture thickness ( $p<0.05$ ) and tissue protection ( $p<0.05$ ) during the corneal suturing assessment. The overall scores of corneal suturing and circular capsulorhexis in the porcine eye in group A were comparable to those in group B ( $p=0.26$  and  $0.87$ , respectively). Group A showed a more positive attitude to withstand the training for more than 4 hours ( $p<0.001$ ), as well as a higher willingness to receive more times of the training in the future ( $p<0.001$ ).

**Conclusions** Training models based on grapes are equal to VR simulators and silicon suture pads to provide solid training tasks for ophthalmology residents to master basic microsurgical skills, and might have advantages in lower economic cost, and easy availability.

**Trial registration number** ChiCTR2000040439.

## INTRODUCTION

The delicate nature of ocular tissues and anatomic components results in low fault tolerance by operators during the actual surgery.<sup>1–3</sup> Therefore, ophthalmic microsurgical training is essential, however, very challenging. Traditionally, the surgical training within the clinical setting (Halstedian method—'see one, do one, teach one'), is based on real patients and may raise actual challenges and difficulties for the patients, trainers and trainees simultaneously (ie, ethical concerns, possibly higher complications or potential lawsuits).<sup>4,5</sup> Wet lab and synthetic simulators are the two currently used training models.<sup>6–10</sup> The wet lab or dry lab uses

## WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ Ophthalmic microsurgical training is essential but challenging for junior ophthalmologists.
- ⇒ There are two kinds of mainstream training models, including wet-lab and virtual reality (VR) modulator for junior ophthalmologists.

## WHAT THIS STUDY ADDS

- ⇒ Grape, as a simulation training model, could be well designed and modified as reliable and solid models for ophthalmology residents to practice microsurgical techniques with less costs and better availability.
- ⇒ Training models based on grapes are equal to VR stimulator for junior ophthalmologists to master the basic microsurgical techniques.

## HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ In addition to artificial model eyes, animal eyes, foam, silicone and VR modulators, fruits can be considered and developed to be another kind of training modulator for junior ophthalmologists.

artificial manufactured eyes, human cadaver or animal eyes. Human cadaver eyes are difficult or unavailable in many ophthalmic institutes.<sup>10</sup> Porcine eyes are commonly used in the wet lab. However, porcine eyes are significantly different from human eyes in tissue and anatomical properties. Additionally, the use of porcine eyes may raise some unexpected regional, ethical concerns or even the risk of disease transmission.<sup>11–13</sup> Recent studies by Dean *et al* suggested that intense training based on manufactured eyes significantly facilitated the rapid acquisition of surgical competence of trabeculectomy and small-incision cataract surgery in primary surgeons.<sup>6,14</sup> However, manufactured eyes might not be well available in some countries. Virtual reality (VR) simulators have been introduced in some competency-based training programmes for ophthalmology residents to build and strengthen their techniques of curvilinear capsulorhexis, pars plana vitrectomy and epiretinal/internal limiting membrane peeling.<sup>6,7,10,15,16</sup> However, in addition to the high purchasing prices, VR simulators have their drawbacks in tissue and size simulations to human eyes. It offers training tasks by set programmes. Therefore, trainees can only



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practice on limited given tasks. Some basic skills, such as incision suturing, cannot be trained on VR simulators.<sup>10 15 17</sup> According to previous studies, VR simulators offer limited options for trainees to adjust the microscopes instantly and accurately focus on the training targets.<sup>6 10 17 18</sup> Moreover, VR simulators offer limited training in hand-eye-foot coordination, which is essential in actual ophthalmic surgery. Finally, VR simulators are not able to provide a realistic tactile sensation for the trainees. All the training feedback is based on digital programming.<sup>17</sup> All these factors may elongate the learning curve for the trainees in adapting themselves to actual surgical instruments. Thus, other training modalities with lower cost and higher availability for the trainees are highly desired. Recently, a series of attractive videos using various fruits to explain the basic idea of surgery was posted on multiple websites for public education.<sup>19</sup> Grapes were also used to have training of suturing under microscopes.<sup>20</sup> Interestingly, two recent randomised clinical trials by Dean *et al* also employed apples and tomatoes in the simulation surgical training.<sup>6 14</sup> However, to the best of our knowledge, there is no clinical trial to evaluate the possibility and reliability of grapes to be used for ophthalmology residents' microsurgical training. Therefore, this study introduces an accessible, standardised fruit model for simulating surgery. This fruit model will be evaluated for its efficacy to establish the interest to learn surgical skills in ophthalmology residents, its ability to strengthen the residents' confidence with ophthalmic microsurgery, and its potential to improve the residents' basic ophthalmic microsurgical skills.

## METHODS

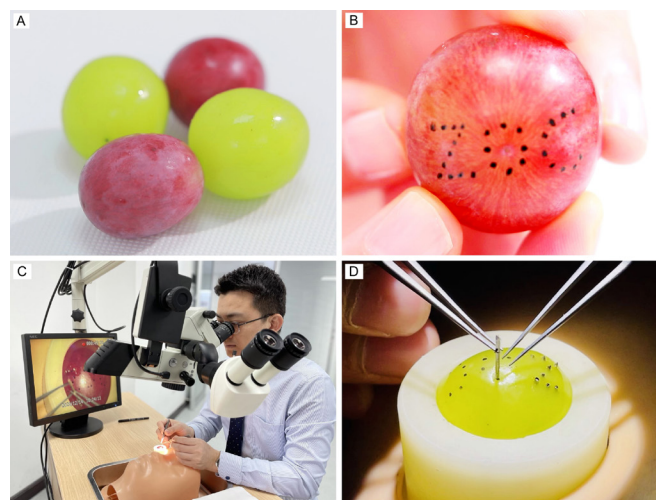
### Participants

Eighty-three first-year ophthalmology residents, who were just enrolled in their residency training programme, were recruited into this study. All the participants were novices at ophthalmic operations, who just completed their medical-school learning and achieved their bachelor's degree. Before training, all participants were asked to view an instructional video demonstrating basic eye anatomy, a brief introduction to the training model they would receive, and a quick guide for using a microscope (zoom in and out, x-y axis moving and focus adjusting). All the participants were randomised 1:1 into two groups. Group A was assigned to finish their ophthalmic microsurgical training on a fruit model, while group B on VR (EYESi; VRmagic, Mannheim, Germany) and silicone skin suture pads. The total duration of the training for each participant was 4 hours. The 4 hours were equally divided into two sessions (2 hours+2 hours). The time interval for the two training sessions ranged from 7 to 10 days for each participant. Participants in each group were blinded to the training details in the other group.

### Pretraining and post-training questionnaire survey

Before the beginning of the training, each participant was asked to answer a questionnaire regarding their microsurgical experience, their confidence level on ex vivo porcine eyes, and their coming role as an assistant surgeon in the realm of ophthalmic surgeries (online supplemental table 1).

After the training, all participants were required to finish a questionnaire regarding their interest in learning microsurgical skills with the models, their willingness to receive more training tasks based on the models, their confidence with ophthalmic micromanipulations on porcine eyes, and their coming role as an assistant who would independently help the surgeon finish ophthalmic microsurgery (online supplemental table 2).



**Figure 1** Training of hand-eye-foot coordination based on the grape model. (A) Fresh grapes with a diameter ranging from 20 to 25 mm; (B) three English letters-ZOC (initial of the Institute) drawn on the surface of the grapes with a black marker Pen (stroke width=1 mm); (C, D) training under the microscope, following the stroke order of the three letters from Z to C under the microscope.

### Training models designing

For better fruit model designing, various kinds of fruits (ie, mango, pitaya, bell pepper) were successfully used and evaluated as training models in our pre-experiment. Finally, the grape was optimal in terms of tissue and size simulation with human eyes. Therefore, fresh grapes with a diameter ranging from 20 to 25 mm were purchased from the market (figure 1A) to serve as a training model in group A. Bright red and green grapes were preferred due to the high contrast sets of colours. Three steps for different training purposes were developed based on grapes (group A) and VR simulators (together with silicone suture pads) (group B).

#### Training step 1: hand-and-eye coordination

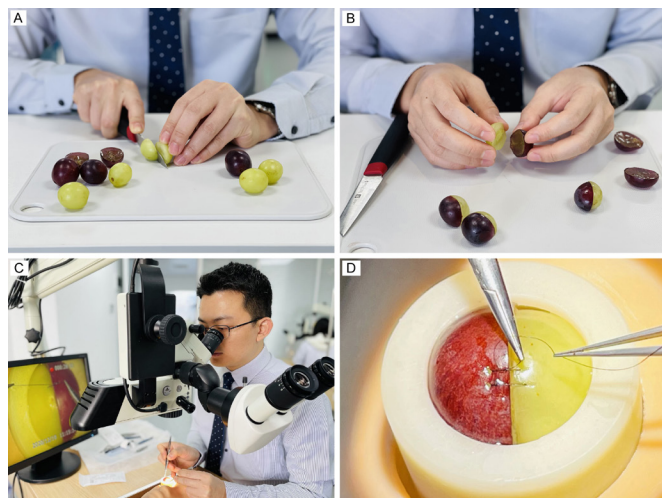
In group A, we drew three English letters-ZOC (initial of the institute) on the surface of the grapes with a black marker pen (stroke width=1 mm). The diameter of each letter ranged from 4 to 6 mm (figure 1B). Next, the participants were required to insert tiny nails into the grape through the letters (diameter=1 mm), following the stroke order of the three letters from Z to C under the microscope (figure 1C,D). All participants were required to repeat the whole task on at least three grapes but could repeat as long as desired to feel fully competent to finish the task under the microscopes.

In group B, hand-and-eye coordination was trained by practising the Navigation Training section on the simulator. Spheres of different sizes were located in different places and depths in the anterior chamber. Trainees were asked to insert and keep the instrument tip inside each sphere. Tissue damage should be avoided.

#### Training step 2: suturing

In group A, two grapes of similar size but different colours (eg, red and green) were chosen as models. The grapes were cut transversely into two halves with a fruit knife (figure 2A). Then, two grape halves with different colours were paired and set into the adapting frame mentioned above (figure 2B). The participants were asked to suture the two halves together with 8/0 silk





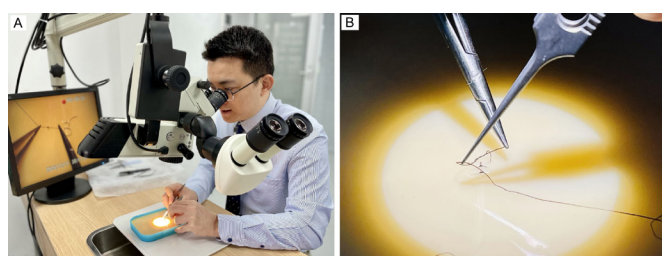
**Figure 2** Training of suturing based on the grape model. (A) Two grapes of similar size but different colours were cut transversely into two halves with a fruit knife; (B) two grape halves with different colours were paired and set into the adapting frame; (C) the participants were asked to suture the two halves together with 8/0 silk sutures under the microscope; (D) the needle distance and span were set 1 mm and 2 mm, respectively.

sutures (figure 2C). The needle distance and span were set 1 mm and 2 mm, respectively (figure 2D). At least eight sutures were required on each incision. The participants were required to finish at least three grapes.

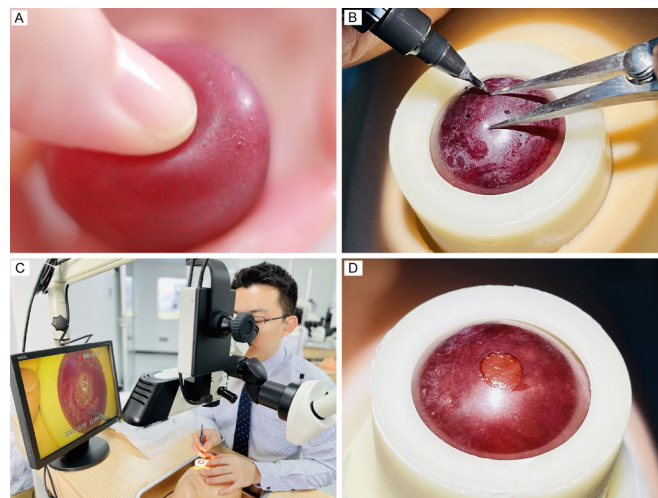
The VR simulator was not able to provide the suturing model. Therefore, in group B, for matching purposes, silicon suture skin pads and 8/0 silk sutures were prepared for practising cornea/skin suturing since suturing is one of the basic microsurgical skills for ophthalmic residents. The participants were asked to suture using the suture pad under the microscope (figure 3A,B). The standard needle distance and span required in this scenario were 1 mm and 2 mm, respectively.

### Training step 3: circular capsulorhexis

In group A, the grape was slightly massaged to soften and to separate the fruit skin easier (figure 4A). Then, the grape was fixed on a supporting frame initially designed for training on porcine eyes. Next, we used a ruler to line out the area (centre of the grape surface under the microscope) and diameter (6 mm) of the capsulorhexis, indicating with a marker pen (figure 4B). Finally, capsulorhexis forceps were used to finish the task. The participants were required to finish the whole task under the microscopes, strictly following the instructional video on performing circular capsulorhexis on human eyes (figure 4C,D).



**Figure 3** Training of suturing based on silicon suture skin pad. (A, B) Silicone suture skin pad and 8/0 silk sutures were prepared for practising cornea/skin suturing under the microscope.



**Figure 4** Training of circular capsulorhexis based on the grape model. (A) The grape was slightly massaged to soften and to separate the fruit skin easier; (B) the grape was fixed on a supporting frame and was lined out the area (centre of the grape surface under the microscope) and diameter (6 mm) of the capsulorhexis; (C, D) Capsulorhexis forceps were used to finish the task under the microscope.

Each participant was required to finish capsulorhexis until they felt fully competent but at least three times.

In group B, participants practised circular capsulorhexis independently on the simulator after a brief introduction provided by the same trainer. Viscoelastic parameters were set to default. Trainees were asked to create a starting flap and to perform circular capsulorhexis using the capsulorhexis forceps simulator. An overall score and the list of subscales have been shown automatically after each practice.

### Assessment after training

After finishing the training steps, each participant was assigned to assess their ophthalmic microsurgical skills based on ex vivo porcine eyes. Freshly enucleated porcine eyes were collected from the slaughterhouse early in the morning and stored in the refrigerator in Dulbecco's phosphate buffered saline (Gibco; Thermo Fisher Scientific, Waltham, MA) at 4°C until usage (used within 8 hours after collecting).

Before the assessment, each participant was asked to watch an instructional video demonstrating the optimal performance of corneal suturing and capsulorhexis. The video covered stepwise illustrations and defined specific deviations that would be considered errors. Additionally, all the participants took a preassessment to practice on porcine eyes for 1 hour (a half-hour in cornea suturing and a half-hour in capsulorhexis) right before the assessment. All operations were performed and recorded in the wet lab on operating microscopes under the supervision of the same surgeon. The supervising surgeon was masked to participant randomisation.

### Module 1: cornea suturing

The porcine eye was fixed in a stabiliser. The supervising surgeon used a 15° knife (Alcon; Alcon Laboratories, Fort Worth, Texas, USA) to create a full-thickness straight corneal incision in the cornea centre, with a length of 5 mm. Viscoelastic was injected into the anterior chamber through the side corneal incision to support the cornea for the upcoming suturing tasks. All participants were asked to suture with three consecutive 2-handed square knots with 10/0 nylon sutures

**Table 1** Scoring criteria of cornea suturing in porcine eye

Length of suture placement on each side L=average length of three sutures (mm)					
One point	$0.75 \leq L \leq 1.25$	0.5 point	$1.25 < L \leq 1.5$ or $0.5 \leq L < 1.25$	0 point	$L > 1.5$ or $L < 0.5$
Uniformity of suture placement length UL=maximum length – minimum length (mm)					
One point	$UL \leq 0.25$	0.5 point	$0.25 < UL \leq 0.5$	0 point	$UL > 0.5$
Spacing of suture placement S=average spacing of three sutures (mm)					
1 point	$1.0 \leq S \leq 1.5$	0.5 point	$1.5 < S \leq 1.75$ or $0.75 \leq S < 1.0$	0 point	$S > 1.75$ or $S < 1.0$
Uniformity of suture placement spacing US = maximum spacing – minimum spacing (mm)					
1 point	$US \leq 0.25$	0.5 point	$0.25 < US \leq 0.5$	0 point	$US > 0.5$
Depth of suture placement D = average (depth of suture placement/cornea thickness)					
1 point	$0.67 \leq D \leq 0.8$	0.5 point	$0.5 < D \leq 0.67$ or $0.8 \leq D < 0.9$	0 point	$D > 0.9$ or $D < 0.5$
Uniformity of suture placement depth UD = (maximum depth – minimum depth)/cornea thickness					
1 point	$UD \leq 0.1$	0.5 point	$0.1 < UD \leq 0.15$	0 point	$UD > 0.15$
Tissue protection					
2 points: Any or combination of the following mistakes: no or very little incision stress; $\leq 1$ slight corneal stroma damage					
1 point: Any or combination of the following mistakes: $\geq 1$ marked incision stress (no viscoelastics refill needed); $\leq 1$ severe corneal stroma damage or $\leq 2$ slight corneal stroma damage					
0 point: mistakes severe than 1 point					
Time T=first attempt to enter the anterior chamber until completion of suturing (min)					
Two points	$T \leq 15$	one point	$15 < T \leq 20$	0 point	$T > 20$

(Alcon; Alcon Laboratories). The resulting corneal suturing eyes from all 83 participants were evaluated by the same experienced surgeon using 6 predefined criteria: suture distance, suture span, suture thickness, suture uniformity, tissue protection and time cost (table 1). The scoring system was developed and validated based on a pre-experiment with a similar resident cohort.

## Module 2: circular capsulorhexis

The porcine eye was fixed in a stabiliser (Mingde Medical; Mingde Medical Device, China). An experienced surgeon performed a clear corneal tunnel incision with a 3.2 mm knife (Alcon; Alcon Laboratories). The same surgeon filled the anterior chamber with a viscoelastic fluid (ivie; Bausch&Lomb, Rochester, New York, USA). The participants were then asked to performed circular capsulorhexis using capsulorhexis forceps. If necessary, the anterior chamber was refilled with viscoelastic by the participant. All 83 capsulorhexis results were analysed by the same experienced surgeon using five predefined criteria: circularity, size, centring of capsulorhexis, tissue protection and time cost (table 2). The

scoring system was developed based on a pre-experiment with a similar resident cohort.

## Economic input and availability analysis between groups

We also performed a rough analysis of the economic input into the two groups. The economic input included the following factors: purchase prices of the fruits and VR simulator, micro-surgical equipment cost and staff cost.

The availability analysis included the data of VR simulators installed in Mainland China, and literature research on Pubmed and Google.com about VR simulators installed all over the world.

## Statistical analysis

Statistical analysis was performed using SPSS Statistical Software, V.25 (SPSS, IBM). Continuous variables are expressed as mean $\pm$ SD and median (range) according to their distributions (Shapiro-Wilk normality test). Categorical variables are described as proportions (%). A p value of less than 0.05 was considered statistically significant.

**Table 2** Scoring criteria of circular capsulorhexis in porcine eye

Capsulorhexis circularity R=minimum rhexis diameter/maximum rhexis diameter					
2 points	$0.85 < R \leq 1.0$	1 point	$0.7 < R \leq 0.85$	0 point	$R \leq 0.7$
Capsulorhexis size S= (minimum rhexis diameter +maximum rhexis diameter)/2 (mm)					
2 points	$5.5 \leq S \leq 6.5$	1 point	$6.5 < R \leq 7.5$ or $4.5 \leq R < 5.5$	0 point	$R > 7.5$ or $R < 4.5$
Capsulorhexis centring C=maximum distance from the centre of rhexis to the centre of pupil (mm)					
2 points	$C \leq 0.5$	1 point	$0.5 < C \leq 1$	0 point	$C > 1$
Tissue protection					
2 points: Any or combination of the following mistakes: Clear cornea tunnel: no or very little incision stress; Cornea: $\leq 1$ slight localised endothelial contact; Lens: No or slight superficial churning of lens fibre					
1 point: Any or $\leq 2$ of the following mistakes: Clear cornea tunnel: marked incision stress (no viscoelastics refill needed); Cornea: $\leq 1$ strong localised or $\leq 2$ slight localised endothelial contact; Lens: $\leq 2$ churning of deep lens fibre, lens displacement					
0 point: mistakes severe than 1 point					
Time T=first attempt to enter the anterior chamber until completion of capsulorhexis (min)					
2 points	$T \leq 5$	1 point	$5 < T \leq 10$	0 point	$T > 10$

**Table 3** Detailed scores of porcine eyes performance of the participants in group A and group B

	Group A (n=42)	Group B (n=41)	P value
Cornea suturing (95% CI)	6.50 (6.20 to 6.80)	6.29 (6.06 to 6.52)	0.26 <sup>a</sup>
Suture distance	0.74 (0.111)	0.71 (0.095)	0.26
Uniformity	0.64 (0.158)	0.60 (0.123)	0.35 <sup>b</sup>
Suture span	0.71 (0.142)	0.66 (0.134)	0.09 <sup>b</sup>
Uniformity	0.65 (0.157)	0.58 (0.118)	0.05 <sup>b</sup>
Suture thickness	0.65 (0.124)	0.62 (0.127)	0.38 <sup>b</sup>
Uniformity	0.57 (0.127)	0.52 (0.864)	0.03 <sup>b</sup>
Tissue protection	0.73 (0.085)	0.68 (0.125)	0.03 <sup>b</sup>
Time cost	1.24 (0.514)	1.30 (0.581)	0.67 <sup>b</sup>
Capsulorhexis (95% CI)	6.19 (5.78 to 6.60)	6.15 (5.81 to 6.49)	0.87 <sup>a</sup>
Circularity	1.26 (0.457)	1.34 (0.378)	0.49 <sup>b</sup>
Size	1.10 (0.336)	1.02 (0.273)	0.29 <sup>b</sup>
Centring	1.28 (0.253)	1.28 (0.275)	0.82 <sup>b</sup>
Tissue protection	1.23 (0.376)	1.31 (0.314)	0.65 <sup>b</sup>
Time cost	1.33 (0.373)	1.20 (0.369)	0.09 <sup>b</sup>

Data were expressed as mean (SD) when otherwise indicated.

Statistical methods: a, Fisher's exact test; b, Mann-Whitney U test

### Human subjects and power calculation

Based on the preliminary results from 10 participants, the mean score for corneal suturing and circular capsulorhexis in the porcine eye after VR training was 6.5 (SD=0.6). The non-inferiority margin was set as 0.4. We used one-sided 97.5% confidence intervals and a power of 0.8 to calculate the sample size. Under a 1:1 randomisation ratio, a total sample size of 72 residents was estimated to show statistical significance concerning the primary endpoint. By considering the drop-out rate as 10%, at least 80 participants should be enrolled. Finally, 83 participants were recruited for the study.

## RESULTS

### Participants characteristics

All 83 participants finished the study, with 42 in group A and 41 in group B. There was no statistically significant difference between the two groups in terms of gender, age and experience in microsurgery (all  $p>0.05$ ).

### Primary outcomes of tasks assessment

Participants in group A acted better than those in group B in terms of the uniformities of suture span ( $p<0.05$ ) and suture thickness ( $p<0.05$ ). Meanwhile, participants in group A had better tissue protection ( $p<0.05$ ) during the incision suturing tasks. The overall scores (out of 10) in corneal incision suturing and circular capsulorhexis showed no statistically significant difference between group A and group B ( $6.50\pm0.1$  vs  $6.29\pm0.1$ ,  $6.19\pm0.2$  vs  $6.15\pm0.2$ ;  $p=0.26$  and  $0.87$ , respectively). The details of the assessment of the task in group A and group B are demonstrated in [table 3](#).

### Change of confidence after training

Before training, participants in both group A and group B showed moderate confidence with practice tasks on the porcine eyes ( $5.5\pm0.4$  vs  $5.4\pm0.3$ ;  $p=0.90$ ) and to be a surgical assistant ( $4.0\pm0.4$  vs  $4.0\pm0.3$ ;  $p=0.90$ ). As for the participants' preferred practice simulators, 59.5% (25/42) in group A chose fruits, and 48.8% (20/41) in group B chose AR simulators ( $p<0.001$ ). Nearly half of the participants in group A (18/42) and group B (18/41) considered a sufficiently long training time

**Table 4** General characteristics and pretraining parameters of the participants in group A and group B

	Group A (n=42)	Group B (n=41)	P value
Gender (male: female)	12 : 30	11 : 30	$>0.999^a$
Age (years)			
Experience of micromanipulations (hours)	0	0	$>0.999^a$
Confidence with practice tasks on the porcine eyes (95% CI)	5.50 (4.76 to 6.24)	5.44 (4.84 to 6.04)	0.90 <sup>b</sup>
Confidence to be a surgical assistant (95% CI)	4.02 (3.60 to 4.68)	3.95 (3.20 to 4.70)	0.88 <sup>b</sup>
Preferred practice modulator	42	41	$<0.001^a$
Fruits	25	2	
AR modulators	3	20	
Porcine eyes	14	19	
Factor considered most important to strengthen confidence	42	41	0.12 <sup>a</sup>
Enough time of modulator practice	18	18	
Enough mentor instruction	8	2	
Enough clinical practice	16	21	

Statistical methods: a, Chi-Square analysis; b, Mann-Whitney U test

with the simulator to be the most important factor for them to strengthen confidence. The participants' general characteristics and pretraining questionnaire were summarised in [table 4](#).

The questionnaire revealed that participants in group A and group B showed an overall positive interest in the training simulator they had received ( $8.50\pm1.45$  vs  $8.61\pm1.48$ ,  $p=0.73$ ). However, group A participants showed a more positive attitude to withstand the training for more than 4 hours ( $4.20\pm0.87$  vs  $2.95\pm1.04$ ,  $p<0.001$ ), as well as higher willingness to receive more times of the training in the future ( $4.27\pm0.78$  vs  $3.33\pm0.94$ ,  $p<0.001$ ). Participants in group A and group B showed significantly increased confidence with practice tasks on porcine eyes and to be a surgical assistant after the training (all  $p<0.05$ ). However, there was no statistically significant difference between the two groups (group A and group B) in terms of confidence with practice tasks on porcine eyes (0.60, 95% CI  $-0.19$  to  $1.38$ ,  $p=0.13$ ) and to be a surgical assistant (0.42, 95% CI  $-0.42$  to  $1.27$ ,  $p=0.32$ ) after the training. The details of the post-training questionnaire are summarised in [table 5](#).

### Economic input and availability analysis

During the training programme, 10 kg of grapes were needed in total. The average weight of a grape was 20 g, and nearly 12 grapes were needed for one trainee. The average price of grapes was ¥50/kg. Therefore, the total price of the grapes was ¥500 (56 pounds). One VR simulator was installed in our institute. The purchase price was ¥1 million (110 thousand pounds).

Because there were eight microscopes installed in the wet lab, eight trainees could accommodate within one time slot. So, only six time slots were needed to finish group A training programmes. Therefore, the total running time in group A was 24 hours (4 hours/trainee $\times$ 6 time slots). Meanwhile, because there was only VR simulator available, the total running time in group B was 164 hours (4 hours/trainee $\times$ 41 time slots). According to the service payment in the institute, ¥100/hour was needed to pay for the labour service. Using this number, the total



**Table 5** Main outcomes and Post-training parameters in group A and group B

	Group A (n=42)	Group B (n=41)	P value
Learning interest with the modulator (95% CI)	8.50 (8.05 to 8.95 )	8.61 (8.14 to 9.08 )	0.73 <sup>a</sup>
Possibility to withstand training for more than 4 hours (95% CI)	4.20 (3.92 to 4.47)	3.00 (2.62 to 3.28)	<0.001 <sup>b</sup>
Willingness to receive more times of training (95% CI)	4.27 (4.02 to 4.51)	3.33 (3.02 to 3.63)	<0.001 <sup>b</sup>
Confidence with practice tasks on the porcine eyes (95% CI)	6.50 (5.98 to 7.02 )	5.90 (5.30 to 6.51 )	0.13 <sup>a</sup>
Pretraining versus post-training (p value)	0.03 <sup>a</sup>	0.28 <sup>a</sup>	
Confidence to be a surgical assistant (95% CI)	5.71 (5.15 to 6.28)	5.29 (4.65 to 5.94)	0.32 <sup>a</sup>
Pretraining versus post-training (p value)	<0.001 <sup>a</sup>	0.007 <sup>a</sup>	
Factor considered most important to strengthen confidence	42	41	0.17 <sup>c</sup>
Enough time of modulator practice	18	15	
Enough mentor instruction	9	4	
Enough clinical practice	15	22	
Total scores of porcine eye performance			
Cornea suturing (95% CI)	6.50 (6.20 to 6.80)	6.29 (6.06 to 6.52)	0.26 <sup>a</sup>
Circular capsulorhexis (95% CI)	6.19 (5.78 to 6.60)	6.15 (5.81 to 6.49)	0.87 <sup>a</sup>

Statistical methods: a, t test; b, Mann-Whitney U test; c, Chi-Square analysis.

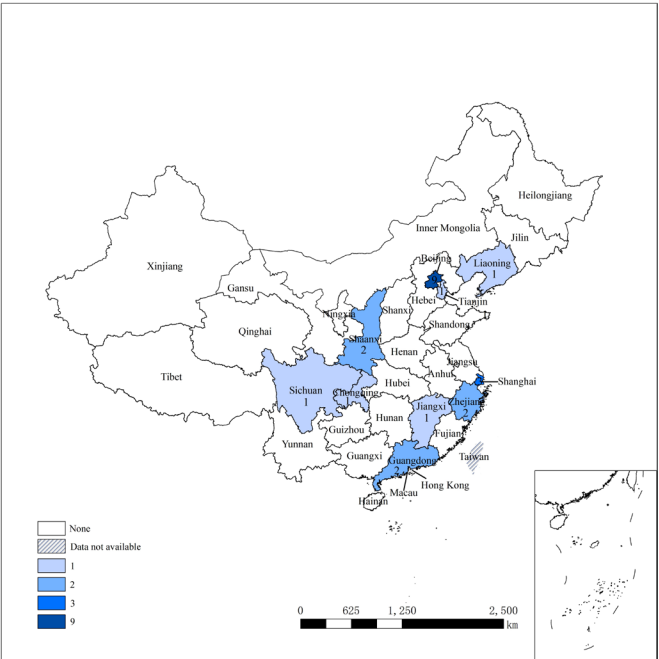
staff costs in group A and group B were ¥2400 (270 pounds) and ¥16 400 (1846 pounds), respectively.

The microsurgical equipment cost (forceps, scissors, needle holders, porcine eye stabilisers, microscopes, sutures) in group A was ¥90 000 (10 128 pounds). In contrast, the cost (forceps, scissors, needle holders, microscope, sutures, silicone suture skin pads) in group B was ¥20 000 (2251 pounds).

According to our comprehensive data collection, there were 21 VR simulators installed in Mainland China. Almost all VR simulators were located in the metropolises and wealthy coastal cities. There were 418 ophthalmology resident training institutes in Mainland China. Thus, the installation rate of VR simulators is 2.9% (12/418). The details are demonstrated in figure 5. According to the literature and internet searching, about 50 countries and regions are equipped with VR simulators. The most frequently reported use of VR simulators occurred in the UK, USA, Germany, France and Denmark.

DISCUSSION

In this study, we demonstrated a detailed protocol for developing the ophthalmic micromanipulation simulation based on grapes, and we showed the fruit model's potential for junior ophthalmologists in their preclinical training. We focused on introducing and assessing a course based on grape for ophthalmology residents to acquire basic microsurgical skills. To the best of our knowledge, this study is the first randomised trial to evaluate the feasibility of grapes as an ophthalmic microsurgical model for ophthalmology residents who were novice at microsurgical performance. Additionally, we set AR simulators plus silicone suture pads as the control to strengthen its reliability with a randomised controlled study. The reason we set the module of hand-and-eye coordination was that all the participants were novice at microsurgical tasks. In our pre-experiment,



**Figure 5** Details and numbers of virtual reality modulators equipped in different areas of mainland China.

we found that the novice usually have poor hand-eye coordination under the microscopes, thus, a preliminary training of the hand-and-eye coordination before stepping into the programme was designed.

Principal findings

Teaching surgical skills to junior doctors is a time-consuming task. Competence in surgical skills requires a large amount of deliberate practice of critical surgical steps. It is not only knowledge required, but also the training is crucial for junior doctors to master different surgical techniques.<sup>1-3 6 15 21</sup> For young doctors in some specialties, such as ophthalmology, the teaching is incredibly challenging. The following factors contribute to the great difficulty in teaching surgical skills to young ophthalmologists.<sup>1-3</sup> First, the delicate nature of ocular tissues and anatomic components results in low fault tolerance by operators during the actual surgery. Second, surgical tasks under the microscope have a long learning curve. It is more likely to experience malpractices when the surgeons do not have enough practice and experience. Third, the devices, especially the VR simulators, might cause an extra economic burden. Fourth, teaching on actual patients raises ethical concerns or even medical disputes. The challenge usually intensifies when the patients are awake under the surgical microscope. Fifth, there are limitations in transferability to the human models, as there is no perfect model of human eyes for surgical training. Finally, adequate supplies (eg, porcine eyes and manufactured eyes) and faculty personnel in wet labs might be troublesome due to funding shortage or other objective limitations. The novel protocols in the current study of how to develop training models with fruits are aimed to provide a reliable and reproducible option for wet-lab training in junior ophthalmologists that are more convenient and economical.

Simulation-based surgical education has been proven to positively impact ophthalmic resident surgical training. This may compromise wet labs, dry labs, digital dry labs and VR simulators.<sup>6-10</sup> They provide a riskless environment for residents to strengthen their surgical skills.<sup>6 8 10 15 22</sup> Surgical skills in cataract

surgery are the leading practices of residents performed on porcine eyes and manufactured eyes. On the other hand, VR simulators provide standardised, quantifiable models.<sup>6 15 23</sup> However, Although there are continuous efforts to develop wet-lab models to simulate live surgery better, training models for junior ophthalmologists are far from adequate, especially for those with little microsurgical training experience. To our best knowledge, the current study is the first one to develop and evaluate three basic ophthalmic micromanipulation skills together for junior ophthalmologists. It was expected that the curriculum in the current study would enrich the teaching models for junior ophthalmologists to strengthen their basic skills excitingly and easily.

Previous studies revealed that confidence is a crucial trait of any physician.<sup>24</sup> Higher confidence levels improve motivation, such as ambition, effort, creativity or persistence during the learning tasks. As recent studies (GLAUCOMA Simulated Surgery (GLASS) and Ophthalmic Learning and Improvement Initiative in Cataract Surgery (OLIMPICS) trials) showed, intense courses are usually developed to increase confidence among medical students.<sup>6 14</sup> Consistent with that, participants in the current study showed moderate confidence in the upcoming practice task and the role as an independent surgical assistant before the training tasks on grape and VR simulators. Interestingly, participants in both groups showed increased confidence mainly after the training tasks. Therefore, we are convinced that the fruit models are equal to VR simulators (together with silicone suture pads) to increase the junior ophthalmologists' confidence in ophthalmic micro manipulations and the role of attending live ophthalmic surgery. In this sense, fruits models may be superior to VR simulators because of their lower economic cost and higher availability. However, participants in group A showed more positive attitude towards the fruit models, as well as higher willingness to receive more times of training based on the fruit models. This might indicate fruit models could be more easily adapted by the trainees to have skill acquisition with longer duration and higher frequency. The silicone suture pads might also be one of the factors leading to lower willingness of the participants in group B.

In our pre-experiment, we were able to find that other kinds of fruits could also be developed and standardised for ophthalmic micromanipulation practice. For instance, bell peppers with different colours could be developed as training models for incision suturing and full-thickness keratoplasty; Mango could be developed for training to perform blepharoplasty (demonstrated in online supplemental materials). In our clinical practice, incision suturing is one of the basic skills for junior ophthalmologists. However, VR simulators do not have the ideal module for them to have enough training. As the main topic of this study is to evaluate whether grapes could be developed for ophthalmology residents to acquire basic skills in ophthalmic microsurgery. Therefore, in our study, group A (fruit group) participants performed all three basic skill practices only based on grapes. However, those in Group B (VR group) performed incision suturing on silicon suture skin pads. This might be one of the advantages of grape-based simulation training model when compared with VR simulators. Moreover, grapes-based simulation training model might have other advantages in terms of size (eg, the trainees could choose the optimal size for practice) and tissue simulation (eg, the trainees could use forceps to peel off the grape skin from the underneath flesh in reality).

The porcine eye assessment revealed that fruit models and VR simulators (together with silicone suture pads) were equal

to strengthen the participants' basic skills in corneal incision suturing and circular capsulorhexis (both  $p < 0.05$ ). The total scores in corneal incision suturing and circular capsulorhexis showed no statistically significant difference. Circular capsulorhexis is one of the most important steps for ophthalmologist to acquire cataract surgery. Therefore, artificial eyes and VR simulators are widely accepted for circular capsulorhexis. Because intense training is one important factor to facilitate skill acquisition, some well designed artificial eyes, such as the CapHex eye has been developed for capsulorhexis practice and contains a reusable eye with a pre-cut entry point, 6 gel lenses and 20 tinted films; enough for 80–100 procedures.<sup>25</sup> Nevertheless, this study indicated that it is reasonable to suggest the fruit as an alternative to VR simulators for ophthalmic resident training in circular capsulorhexis. Regarding corneal suturing, it was interesting to see that participants in group A performed better than those in group B in terms of the uniformities of suture span ( $p < 0.05$ ) and suture thickness ( $p < 0.05$ ). In addition, participants in group A had better tissue protection ( $p < 0.05$ ) during incision suturing. We assumed that this was attributed to the better simulation of tissue toughness and stereo shape of grapes compared with the silicon suture skin pads.

### Strengths and limitations

This study is the first randomised control trial suggested that training course based on grapes could be an additional one when VR modulators are available. Also, it could be introduced as a solid and reliable course when VR modulator are not available. However, our study has several limitations. First, time constraints did not allow for an extensive training curriculum, and it might limit our ability to evaluate more surgical skills during this study. Therefore, only three basic microsurgical skills were incorporated into the training system based on grapes models and VR simulators. Second, only one kind of fruit (grape) was used to develop standard training models for basic microsurgical skills in group A. Although we found various kinds of fruits suitable for different training models in our pre-experiment, this study did not provide more reliable data using other fruits. However, our pre-experiment and the videos posted online give us the confidence that it was reasonable to expect that other kinds of fruits could also be developed and be valid for microsurgical skills training. Third, we did not have a long-term assessment of the efficacy of the fruit models for the ophthalmology residents to develop their surgical skills. Fourth, only one VR simulator was equipped in our training centre, which is typical with other centres nationwide and worldwide. The shortage of VR simulators is one of the major limitations to its broad popularisation, which also prevents its full utility in the residents' training. Finally, as silicone suture pads were adapted in group B, the VR simulator in the current study could not reasonably match the training models we developed based on the grapes, which would affect internal validity.

### CONCLUSIONS

The teaching of the junior ophthalmologist is time-consuming, and various supplies such as microscopes, porcine eyes, artificial manufactured eyes, VR simulators were needed in the training programme. The fruit models we developed in the current article would provide a reliable addition for training basic microsurgical skills in junior ophthalmologists. Fruit models were able to increase the trainees' confidence with

porcine eye training and the attending role as an assistant in the realm of ophthalmic surgery. In addition, fruit training models might offer their advantages in lower economic cost and easy availability. We are looking forward further studies comparing and introducing various methods and materials for ophthalmology residents to improve efficiency in wet lab training or performance during initial surgical assistance experiences.

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Supplementary Table 1. Questionnaire before the training

Question	Answer
1. Do you have any experiences performing ocular surgeries under a microscope?	<div><input type="checkbox"/>Yes</div> <div><input type="checkbox"/>No</div> <div><input type="checkbox"/>Not clear</div>
2. If yes, please give a rough estimation of the total hours you have spent on it	<div>_____hours</div> <div><input type="checkbox"/>Not Clear</div>
3. What is your confidence level with the following practice tasks that will be performed on the porcine eyes?	<div>From 1-10; 1=least confidence, 10= highest confidence.</div> <div>1 2 3 4 5 6 7 8 9 10</div>
4. Now, if you have an opportunity to be a first assistant for the surgeon to finish an ocular surgery, and what is your confidence level to finish your task without extra assistance from other ones?	<div>From 1-10; 1=least confidence, 10= highest confidence.</div> <div>1 2 3 4 5 6 7 8 9 10</div>

5. Which kind of teaching modulator do you prefer to when you START your learning of practice under a microscope?	<input type="checkbox"/> Fruits  <input type="checkbox"/> AR modulator  <input type="checkbox"/> Porcine eyes
6. Which one of the following factors do you consider the most important for you to strengthen your confidence with the coming tasks as an assistant for the surgeon?	<input type="checkbox"/> Enough time of modulator practice  <input type="checkbox"/> Enough mentor instruction  <input type="checkbox"/> Enough clinical practice

Supplementary Table 2 Questionnaire after training

Question	Answer
1. What is your interest level with the training model you have received?	From 1-10; 1=least interest, 10= highest interest.  1 2 3 4 5 6 7 8 9 10
2. Now, since you have received 4 hours of micromanipulation training. With the current method, you think you can withstand the possibility of training for more than 4 hours.	From 1-5; 1=strongly disagree, 5=strongly agree  1 2 3 4 5
3. Now, since you have received 4 hours of micromanipulation training. With this method, you are willing to receive more training?	From 1-5; 1=strongly disagree, 5=strongly agree  1 2 3 4 5
4. What is your confidence level with the following practice tasks will be performed on the porcine eyes?	From 1-10; 1=least confidence, 10= highest confidence.  1 2 3 4 5 6 7 8 9 10
5. Now, if you have an opportunity to be a first-assistant for the surgeon to finish a ocular surgery, and what is your confidence level to finish your task without extra assistance from other ones?	From 1-10; 1=least confidence, 10= highest confidence.  1 2 3 4 5 6 7 8 9 10



<p>6. Which one of the following factors do you consider the most important for you to strengthen your confidence with the coming tasks as an assistant for the surgeon?</p>	<p><input type="checkbox"/> Enough time of modulator practice</p> <p><input type="checkbox"/> Enough mentor instruction</p> <p><input type="checkbox"/> Enough clinical practice</p>
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