Propensity and quantification of aerosol and droplet creation during phacoemulsification with high-speed shadowgraphy amidst COVID-19 pandemic

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Running title: Aerosol and droplet during phacoemulsification

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Key words: aerosol, COVID-19, SARS-CoV-2, cataract, phacoemulsification

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Abstract

Purpose: To study propensity of aerosol and droplet generation during phacoemulsification using high-speed shadowgraphy and quantify its spread amidst COVID-19 pandemic.

Setting: Aerosol and droplet quantification laboratory

Design: Laboratory study.

Methods: In an experimental set up, phacoemulsification was performed on enucleated goat eyes and cadaveric human corneo-scleral rims mounted on an artificial anterior chamber. Standard settings for sculpt and quadrant removal mode were used on Visalis 100 (Carl Zeiss Meditec, Germany). Microincision and standard phacoemulsification were done using titanium straight tips (2.2 and 2.8 mm in diameter). The main wound incisions were titrated equal to and larger than the sleeve size. High speed shadowgraphy technique was used to detect the possible generation of any droplets and aerosols. The visualization and quantification of size of the aerosols and droplets along with calculation of their spread were the main outcome measures.

Results: In longitudinal phacoemulsification using a peristaltic pump device with a straight tip, no aerosol generation was seen in a closed chamber. In larger wounds, there was a slow leak at the main wound. The atomization of balanced salt solution was observed only when the phaco tip was completely exposed next to the ocular surface. Under this condition, the nominal size of the droplet was ~ 50 µm and the maximum calculated spread was 1.3 meters.

Conclusions: There was no visible aerosol generation during microincision or standard phacoemulsification. Phacoemulsification is safe to perform in the COVID-19 era by taking adequate precautions against other modes of transmission.

Introduction

Severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) infection has been declared as a global pandemic by World Health Organisation since March 2020.[1] Its spread to health care workers due to close proximity to patients has been a reason for concern all over the world.[2] Person-to-person transmission occurs primarily via direct contact or through droplets spread by coughing or sneezing from an infected individual.[3] Surgical procedures are also deemed a risk factor after a series of surgeons were reported as COVID-19 positive in China.[4] There is a world-wide concern that phacoemulsification, which is the most widely performed type of cataract surgery at present, might release aerosols and droplets. These may transmit the infection within the operating room and its air-handling units. Based on this hypothesis, recommendations were made in the past to stop elective cataract surgeries.[5] SARS-CoV-2 virus may be present in the tears and conjunctival secretions of infected COVID-19 patients.[6,7] Since the prevalence of the virus in the conjunctiva is very low, the transmission of the same through ocular surface and ocular fluids has been controversial.[8]

Aerosol and droplet generating medical procedures release particles as small (size <20 μm) and large droplets (>20 μm).[9] Aerosols and droplets of size ≥ 6 μm may get trapped in the upper respiratory tract.[9] High speed shadowgraphy is a widely used imaging technique to study these.[10] It uses a strobe light source such as a pulsed laser or light emitting diode (LED) which is focused towards the camera creating a white image. The dark outline of fast-moving objects can then be captured using a sufficiently fast shutter (short exposure time). In this study, we investigated the propensity of aerosol generation during phacoemulsification using high speed shadowgraphy.

Methodology

This experimental study was approved by the institutional research and ethics committee of Narayana Nethralaya Multispecialty Hospital, Bangalore, India and conducted in accordance with the tenets of the Declaration of Helsinki. This approval was secured for the part of the study involving the use of human ocular tissue. The study was performed in collaboration with the Indian Institute of Science, Bangalore, India. The study design was as follows: [A] Enucleated goats' eyes were carefully inspected for uniformity and clarity of the ocular surface. The prepared eyes were mounted on a mannequin head and were exposed in a way such that the cornea, limbus and some part of sclera were clearly visible for surgical manoeuvring (Figure 1A)**;** [B] The human corneoscleral button was loaded onto a Barron artificial anterior (Figure 1B) chamber (Katena, Denville, NJ) connected by tubing to a 10 mL syringe filled with balanced salt solution (BSS). The Visalis 100 (Carl Zeiss Meditec AG, Jena, Germany), a peristaltic pump device with titanium straight tips (21g biconical 2.2 straight 15° and 20g 2.8 straight 30°), was used for the procedure. The Sculpt (80 mmHg vacuum, 18 cc/min flow rate, 40 µm of ultrasound) and Quadrant removal modes [350 mmHg vacuum, 34 cc/min flow rate and 60 µm ultrasound] were used in linear and fixed modes (Figure 1C).

The shadowgraphy technique involved the use of high-speed camera. The Mini-UX100 (Photron USA Inc., San Diego, USA) was coupled with a macro lens (ATX 100, 100 mm, f2.8D; Kenko Tokina Co., Ltd., Tokyo, Japan) for imaging. The resolution of the camera was 1280 x 1024 pixels. The aperture was set to f/32 for maximum depth of field. The illumination using a high-power LED source (Constellation 120, Veritas) was positioned opposite to the camera and used in a continuous mode. The experimental setup was inserted in between the light and the camera for high speed shadowgraphy. The camera was manually triggered to acquire images during the procedure. The acquisition rate was fixed at 500 frames per seconds (fps) and at a shutter speed of 1/16000 second (Figure1D). In both models, i.e., the goat eye on mannequin and cadaveric human corneo-scleral rim in the artificial anterior chamber, only main port incisions were made. The tips and sleeves were used in the following combinations:

1. 2.2 mm incision and 2.2 tip and sleeve
2. 2.8 mm incision and 2.2 tip and sleeve
3. 3.2 mm incision and 2.2 tip and sleeve
4. 2.8 mm incision and 2.8 tip and sleeve
5. 3.2 mm incision and 2.8 tip and sleeve

Nucleotomy was done in sculpt and quadrant removal mode after embedding the phacotip within the nucleus. The same was repeated after exposing the tip of the phaco probe and keeping it in close proximity to the ocular surface.

A simple one-dimensional calculation was used to calculate the spread distance of the droplets. An airborne droplet of diameter D and with a horizontal velocity u_d can be acted upon by the ambient convection velocity (u_{air}) which is introduced by the high efficiency particulate air filtration system present in the operating theatre.[11] Under such circumstances, the appropriate governing drag equation is given below[11]:

$$\frac{du_p}{dt} = \frac{18}{r^2}\frac{\rho_f \mu_f}{\rho_d}\frac{u_{rel}(u_{air}-u_d)}{u_{rel}} \qquad [1]$$

where $u_{rel} = \sqrt{(u_{air} - u_d)^2 + v_d^2}$, r = D/2, v_d is the settling rate (measure of velocity) of the droplet, μ_f is the viscosity of air (=18.37×10^{-6} Pa.sec), ρ_f is the density of air (=1.184 kg/m^3), ρ_d is the density of droplet (=997 kg/m^3), g is the acceleration due to gravity (=9.81 m/sec^2) and D is the diameter of the droplet. The value of u_{air} was estimated to be ~ 0.6 m/s which was as per the certified inspection report of the operating theatres at the Narayana Nethralaya eye hospital. The rated capacity of the air-handling units in our operating theaters (3 in number) ranged from 2364 to 2653 ft^3/min and the number of air changes per hour was not less than 40. The droplet evaporates as well as settles under gravity simultaneously. The evaporation timescale can be estimated from the D^2 law while the appropriate settling timescale may be estimated from the Stokes equation as follows[11]:

$$v_d = (\rho_d - \rho_f)\frac{gD^2}{18\mu_f} \qquad [2]$$

Assuming the point of droplet ejection (location of human cornea) is ~1 m from the floor, the timescale of droplet settling on a surface can be obtained from equation 2 as follows:

$$t_s = \frac{1}{v_d} = \frac{36\mu_f}{(\rho_d - \rho_f)gD} \qquad [3]$$

By multiplying the droplet velocities calculated from the shadowgraph images with ts, their spread distance can be calculated. These distances were plotted as a function of droplet diameter. The shadowgraph image was binarized and analysed using “Particle Analyzer” plugin in ImageJ (open source JAVA based image processing software) to quantify the diameters of the aerosols and droplets.

Results

In the goat eyes mounted on a mannequin, phacoemulsification was performed using different incision and tip-sleeve combinations. The dynamic optical images were recorded as black shadows against a white background using high speed shadowgraphy. There was no release of aerosols in a closed chamber surgery where the size of tip sleeve and incisions were similar (Figure 2A and video in supplementary material). The leakage of fluid from the main wound was seen on the shadowgraph but there was no generation of aerosols when the incision size was larger than the sleeve tip size (Figure 2B and video in supplementary material). The atomisation of water droplets and generation of aerosols was noted when the tip was exposed and close to the water droplets on the corneal surface (Figure 2C and video in supplementary material). Figure 2D shows leaking fluid from the main wound (blue arrow) but no optical shadows of aerosols. Figure 2E shows atomisation of balanced salt solution (BSS) when the exposed phaco tip was kept close to the ocular surface. Figure 2F shows a high speed shadowgraphy image where optical shadows of large droplets released close to the exposed part of the tip are indicated by the blue arrow.

The procedure was repeated on cadaveric human corneo-scleral rim mounted on an artificial anterior chamber model. The results were similar to those in the goat eye model. The aerosols were seen only when the tip was exposed and kept close to the corneal surface (Figures 3A-B and video in supplementary model). The aerosol formation happened only when the exposed part of the tip came in direct contact (Figure 4A) with balanced salt solution outside the ocular surface. The nominal droplet size distribution was extracted from the shadowgraph, and illustrated in Figures 4B and 4C. Figure 4D shows that the nominal diameter of the aerosolised droplet was ~50 μm. As shown in Figure 4E, the spread distance of the droplet increased for diameters ranging from 30 to 50 μm and then decreased monotonically for larger droplets. From the high-speed shadowgraphs, the value of u_d used for these calculations was estimated as ~ 1 m/s.

Discussion

Aerosol generation during phacoemulsification became a major concern amongst ophthalmic surgeons after dissemination of videos of aerosol production in fluorescein stained saline water by Wong et al.[12] Darcy et al. demonstrated profuse aerosolization using corneo-scleral rim mounted on an artificial anterior chamber model.[13] In another video using a model eye, Wong et al. highlighted that there was less chance of aerosol visible outside the eye and even lesser with forward movement of phacoemulsification probe.[14] The integrity of the model eye was dissimilar to the normal cornea. Therefore, the earlier results cannot be extrapolated to the human cornea.[12-14] We used an enucleated goat eye in this study as its role as a training model for phacoemulsification has already been established.[15] The artificial anterior chambers are utilised in corneal graft surgeries. We used human cadaveric corneoscleral rim mounted on an artificial anterior chamber to simulate the experimental setting used by Darcy et al.[13] Published literature is not available to validate the efficacy of this model for phacoemulsification.

The shadowgraph technique is based on the shadow cast on the recording plane (in this case the camera sensor) due to refractive deflection of the incident light rays caused by the density difference between air and object (aerosols in this case).[16] Although an imaging technique like the Schiliren[17] may possess better resolution and lower detection limit, shadowgraph is simpler to implement and adequately efficient when done at high frame rate (500 fps) and using a fast shutter speed (1/16000 second). Since the particle size in aerosolised pathogen transmission ranged between 0.05- 500 μm[18], the resolving power of the imaging system in addition to the acquisition rate was also critical in determining the lower limit of the droplet detection. Based on the camera settings and illumination light source power spectrum, a resolution of ~20 μm per pixel was possible (Figures 3 and 4).

Phacoemulsification works on the principle of piezoelectric effect.[19] There was a significant amount of heat generated at the incision site during the procedure, which was usually dissipated from the wound by the irrigating fluid.[20] In our setup, we used the longitudinal or axial mode of phacoemulsification as it caused more heat build-up at the tip in comparison to the torsional mode.[21] Since there was a lot of heat generated during the procedure, the formation of aerosols was expected. In contrast to the earlier videos[12-14], we did not see any aerosol generation in either of our models. This was true for co-axial micro incision cataract surgery and standard phacoemulsification performed in a closed chamber. There was minimal liquid leak seen at the main wound.[22] This finding was independent of the energy used in sculpt or quadrant mode. In cases where the incision was large, there was a slow leak taking place at the main port. There were no visible aerosols (large droplets) generated even in this setting. This is because the exposed part of the tip was near the center of the eye and in direct contact with the nucleus. The part in contact with the wound was cushioned by the sleeve and the continuous flow of fluid on its side dissipated all the heat that was generated.

Aerosol formation happened only when the exposed part of the tip came in direct contact (Figure 4A) with balanced salt solution due to the atomisation of salt solution secondary to the heat generated. With a nominal droplet size of ~50 µm, the spread of infection is highly dependent on the distance travelled by the ejected droplet. The final distance travelled by the droplet was dependent on both the evaporation time scales and was determined from the smaller of the two quantities. As shown in Figure 4E, the spread distance could be as high 1.3 m or 4.3 feet. This distance decreased with larger droplet sizes since the droplet motion was governed by the settling timescale for larger droplets and by the evaporation as well as setting timescales for smaller droplets. If actual viscoelastic materials were used instead of BSS (Figures 3A, 3B and 4A), then the generation and spread of aerosols and droplets was intuitively expected to be less as the viscosity of surgical viscoelastic materials is greater than BSS. Thus, this would make surgical viscoelastic materials more resistant to aerosol and droplet formation. But these findings weren’t relevant to the actual scenario of phacoemulsification as phacoemulsification is always recommended to be performed inside the anterior chamber away from the corneal lip.

To the best of our knowledge, there are no studies in peer reviewed literature that demonstrated visible or invisible aerosol generation during phacoemulsification. We did not test longitudinal and torsional mode separately. We used a straight tip only. Flared tips have been known to produce more heat at the exposed part.[23,24] Therefore, the same results may not be applicable to other tips. This study was performed with the aim of assessing the risk of transmission of SARS-CoV-2 virus from infected patients to the operating surgeon, nurses and technicians during the procedure. However, these results cannot shed light on the viral load present in invisible aerosol. The SARS-CoV-2 may be transmitted through asymptomatic carriers[25] and may occur in the conjunctiva of 2% of symptomatic patients[6,7]. Further, the aerosols generated were from the balanced salt solution moving within the eye and not from the aqueous humour as aqueous is washed off after making an entry and injecting viscoelastic in the eye.

Virus present on the ocular surface could pose a threat to cataract surgeons.[6] Here treatment with topical povidone iodine for 2 minutes, prior to cataract surgery, reduced the virus count to below detectable levels.[26] To conclude, phacoemulsification can be considered as a safe surgery with minimal or no risk of aerosol generation. To our best knowledge, there is no known transmission of COVID-19 through phacoemulsification and this study supports it. We recommend covering the face with a mask during the procedure to minimize the risk from invisible or smaller droplets. Cleaning of the ocular surface with betadine before the procedure, use of similar sized tip, sleeve and incision, and ultrasound power usage only after the tip is completely inside the anterior chamber would reduce or eliminate the risk of transmission. Due to the fear of posterior capsular rupture, there is a common tendency (not advisable though) of emulsifying the last quadrant of the nucleus in the anterior chamber near the main port.[27] If some part of the tip was exposed in this process, there may be plumes of white smoke and droplets particularly in harder cataracts requiring higher ultrasound energy. A limitation was that ultrasound induced aerosolization may be proportional to the fluid flow amount, height of bottle, fluid pressure inside the anterior chamber and the amount of ultrasound power. These need to be investigated in future studies.

WHAT WAS KNOWN

- The SARS-Cov-2 virus can spread through aerosols and droplets.
- In ophthalmology, procedures exist which may have the propensity to create aerosols and droplets.

WHAT THIS PAPER ADDS

- There were no aerosols or droplets generated during phacoemulsification in experimental models using animal and human tissue.
- Profound droplets where created only when the phaco tip was in close proximity to the exterior ocular surface, which wasn't a true representation of phacoemulsification.
- Phacoemulsification is a safe procedure to perform for cataract surgeons while maintaining precautions against other forms of transmission.

References

1. World Health Organization. WHO Director-General's opening remarks at the media briefing on COVID-19. Accessed March 11, 2020. Available at https://www.who.int/dg/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020
2. The Lancet. COVID-19: protecting health-care workers. *Lancet*. 2020;395(10228):922.
3. Rothan HA, Byrareddy SN. The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak. J Autoimmun 2020;109:102433.
4. Liu Z, Zhang Y, Wang X, Zhang D, Diao D, Chandramohan K, Booth CM. Recommendations for Surgery During the Novel Coronavirus (COVID-19) Epidemic. Indian J Surg doi:10.1007/s12262-020-02173-3.
5. Available at https://www.rcophth.ac.uk/wp-content/uploads/2020/04/RCOphth-UKISCRS-COVID-cataract-surgery-guidance-FINAL-170420.pdf. Accessed April 18,2020.
6. Kumar K, Prakash AA, Gangasagara SB, Rathod SBL, Ravi K, Rangaiah A, Shankar SM, Basawarajappa SG, Bhushan S, Neeraja TG, Khandenahalli S, Swetha M, Gupta P, Sampritha UC, Prasad GNS, Jayanthi CR. Presesnce of viral RNAof SARS-CoV-2 in conjunctival swab specimens of COVID-19 patients. Indian J Ophthalmol 2020;68:1015-7
7. Xia J, Tong J, Liu M, Shen Y, Guo D. Evaluation of coronavirus in tears and conjunctival secretions of patients with SARS-CoV-2 infection. J Med Virol doi:10.1002/jmv.25725.
8. Seah I, Agrawal R. Can the Coronavirus Disease 2019 (COVID-19) affect the Eyes? A Review of Coronaviruses and Ocular Implications in Humans and Animals. Ocul Immunol Inflamm 2020;28(3):391- 395.

9. Tellier R. Review of aerosol transmission of influenza A virus. Emerg Infect Dis 2006;12(11):1657- 1662.

10. Castrejón-Pita JR, Castrejón-García R, Hutchings IM. High Speed Shadowgraphy for the Study of Liquid Drops. In: Klapp J, Medina A, Cros A, Vargas C, (eds). *Fluid Dynamics in Physics, Engineering and Environmental Applications. Environmental Science and Engineering (Environmental Engineering)*. Springer Inc, 2013.

11. Sirignano WA. Fluid Dynamics and Transport of Droplet and Sprays. Cambridge University Press, 1999.

12. Wong RS, Banerjee P, Kumaran N. Aerosol generated procedure in intraocular surgery. Accessed May 13, 2020. https://www.youtube.com/watch?v=0pjkNFwIHCA.

13. Darcy K, Liyanage S. Aerosol during phaco (cataract surgery). How to make cataract surgery safe during Covid-19. Accessed May 18, 2020. https://www.youtube.com/watch?v=8LGwI9LIYmU.

14. Wong RS, Banerjee P, Kumaran N. Aerosol generation in model eye phacoemulsification. Accessed May 5, 2020. https://www.youtube.com/watch?v=bGNezVnj01M.

15. Dada VK, Sindhu N. Cataract in enucleated goat eyes: training model for phaco-emulsification. J Cataract Refract Surg 2000;26(8):1114- 1116.

16. Merzkirch, W. Density sensitive flow visualization. In: Emrich RJ, eds. *Methods of Experimental Physics*. Academic Press, 1981.

17. Tang JW, Nicolle AD, Pantelic J, Jiang M, Sekhr C, Cheong DKW, Tham KW. Qualitative real-time schlieren and shadowgraph imaging of human exhaled airflows: an aid to aerosol infection control. PLoS One 2011;6:e21392

18. Gralton J, Tovey E, McLaws ML, Rawlinson WD. The role of particle size in aerosolised pathogen transmission: a review. J Infect 2011;62:1- 13.

19. Parsloe CF, Twomey JM. Safety of phacoemulsification in a patient with an implanted deep brain neurostimulation device. Br J Ophthalmol 2005;89:1370- 1371.

20. Bradley MJ, Olson RJ. A survey about phacoemulsification incision thermal contraction incidence and causal relationships. Am J Ophthalmol 2006;141:222- 224.

21. Zacharias J. Thermal characterization of phacoemulsification probes operated in axial and torsional modes. J Cataract Refract Surg 2015;41:208- 216.

22. Berdahl JP, DeStafeno JJ, Kim T. Corneal wound architecture and integrity after phacoemulsification evaluation of coaxial, microincision coaxial, and microincision bimanual techniques. J Cataract Refract Surg 2007;33:510- 515.

23. Zacharias J. Laboratory assessment of thermal characteristics of three phacoemulsification tip designs operated using torsional ultrasound. Clin Ophthalmol 2016;10:1095- 1101.

24. Demircan S, Ataş M, Göktaş E, Başkan B. Comparison of 45-degree Kelman and 45-degree balanced phaco tip designs in torsional microcoaxial phacoemulsification. Int J Ophthalmol 2015;8:1168- 1172.

25. Bai Y, Yao L, Wei T, Tian F, Jin D, Chen L, Wang M. Presumed Asymptomatic Carrier Transmission of COVID-19. JAMA 2020;323:1406-1407.

26. Kariwa H, Fujii N, Takashima I. Inactivation of SARS coronavirus by means of povidone-iodine, physical conditions and chemical reagents. Dermatology 2006;212 Suppl 1(Suppl 1):119- 123.

27. Chakrabarti A, Nazm N. Posterior capsular rent: Prevention and management. Indian J Ophthalmol 2017;65:1359-69

Figure Legends

Figure 1: Experimental set up. [A] Enucleated goat eye mounted on a mannequin after ensuring regularity and clarity of ocular surface. [B] Cadaveric human corneo scleral rim loaded on Barron's artificial anterior chamber (Katena, Denville, NJ) connected by tubing to a 10 mL syringe filled with balanced salt solution (BSS). [C] Settings for quadrant removal mode of phacoemulsification on Visalis 100 (Carl Zeiss Meditec, Germany) [D] Optical setup for high speed shadowgraphy using the Mini-UX100 high-speed CCD camera coupled with macro lens for imaging.

Figure 2: Clinical and shadowgraphy images in enucleated goat eye mounted on a mannequin [A] Clinical photo of goat's eye with phacoemulsification probe and 21g biconical 2.2 straight 15° titanium tip inserted through a 2.2 mm corneal main wound [B] High-speed shadowgraphy image showing no optical shadows of aerosols captured during microincision cataract surgery. [C] Clinical photo of phacoemulsification probe and 20g 2.8 straight 30° titanium tip inserted through 3.2mm corneal main wound. [D] High-speed shadowgraphy showing leaking fluid from the main wound (blue arrow) but no optical shadows of aerosols [E] Atomisation of balanced salt solution (BSS) was seen when exposed phaco tip was kept close to ocular surface. [F] High-speed shadowgraphy image showing optical shadows of large droplets released close to the exposed part of the tip (blue arrows)

Figure 3: Clinical and shadowgraphy images in cadaveric human corneo scleral rim mounted on Barron's artificial anterior chamber. [A] Clinical photo showing aerosol generation at the tip of exposed phaco tip kept close to the main wound. [B] High speed shadowgraphy image showing shadows of large droplets released close to the tip.

Figure 4: Quantitative analyses of droplets created when probe was close to the ocular surface. [A] Shadowgraph of the cadaveric human corneo scleral rim. [B] Magnified view of the same. [C] Image is binarized and analysed using “Particle Analyzer” plugin in ImageJ (open source JAVA based image processing software). Red circles indicate the detected droplets. [D] Droplet size distribution. [E] Plot of droplet spread distance vs. droplet diameter. (Inset) shows the condition of calculations where the height of the cornea on the operating table was assumed to be ~1 m, the velocity of the ejected droplet was u_p, the settling velocity of the droplet was v_p and the room convection was u_{air}.

Video Legend

The video shows high-speed shadowgraphy done to test aerosol and droplet generation during microincision and standard phacoemulsification in enucleated goat eye mounted on a mannequin and cadaveric human corneo scleral rim mounted on Barron’s artificial anterior chamber model. No optical shadows were seen when the phaco probe was inside the eye irrespective of the size of main wound. The atomisation of balanced salt solution was seen when the phaco tip was completely exposed close to the ocular surface.

This experimental study showed that cataract surgery was very safe and its propensity to spread aerosols was non-existent. Droplets were created but were large enough to settle down before evaporation.

Figure 1

Click here to access/download;Figure;FIGURE 1.tif

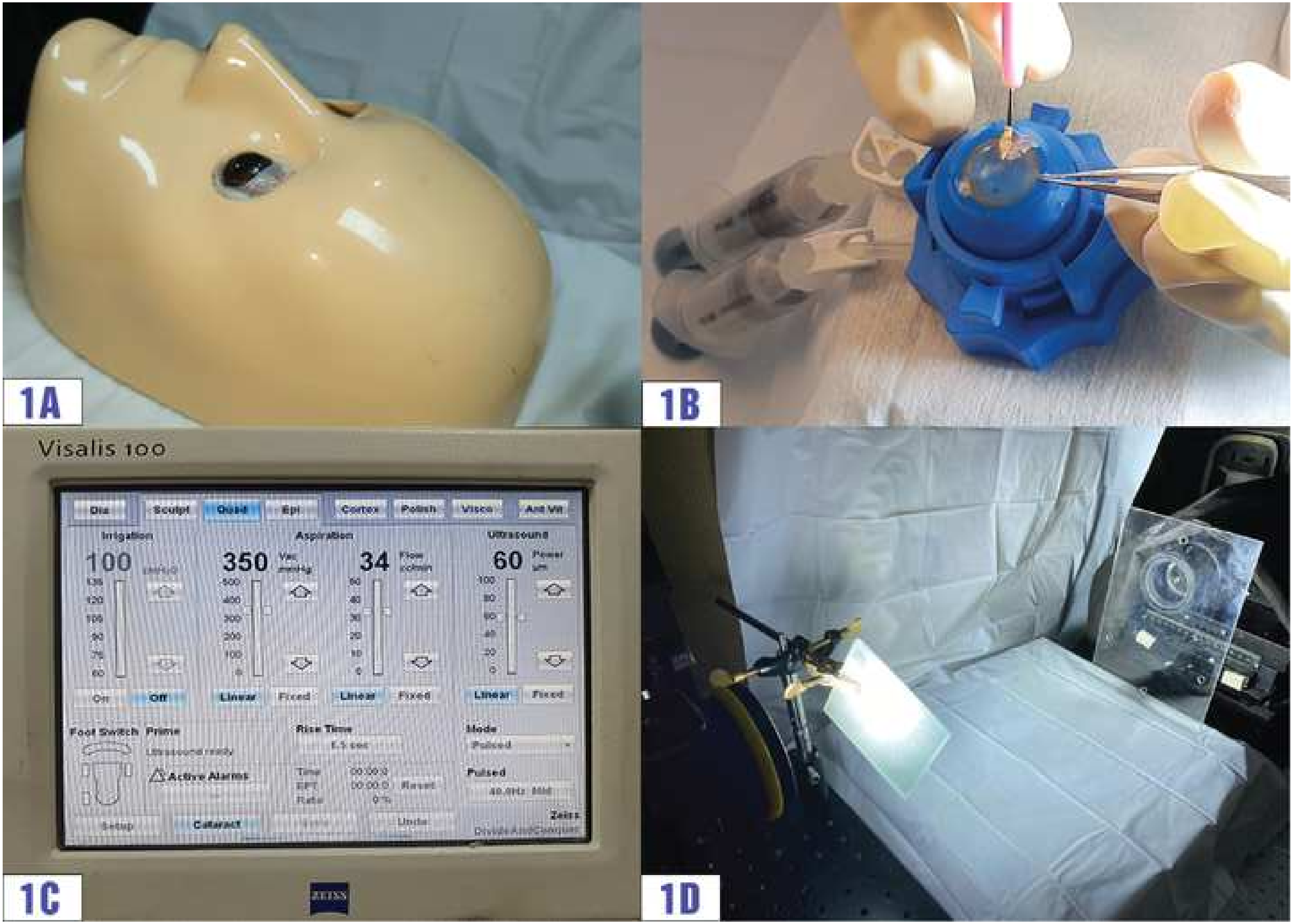


Figure 2

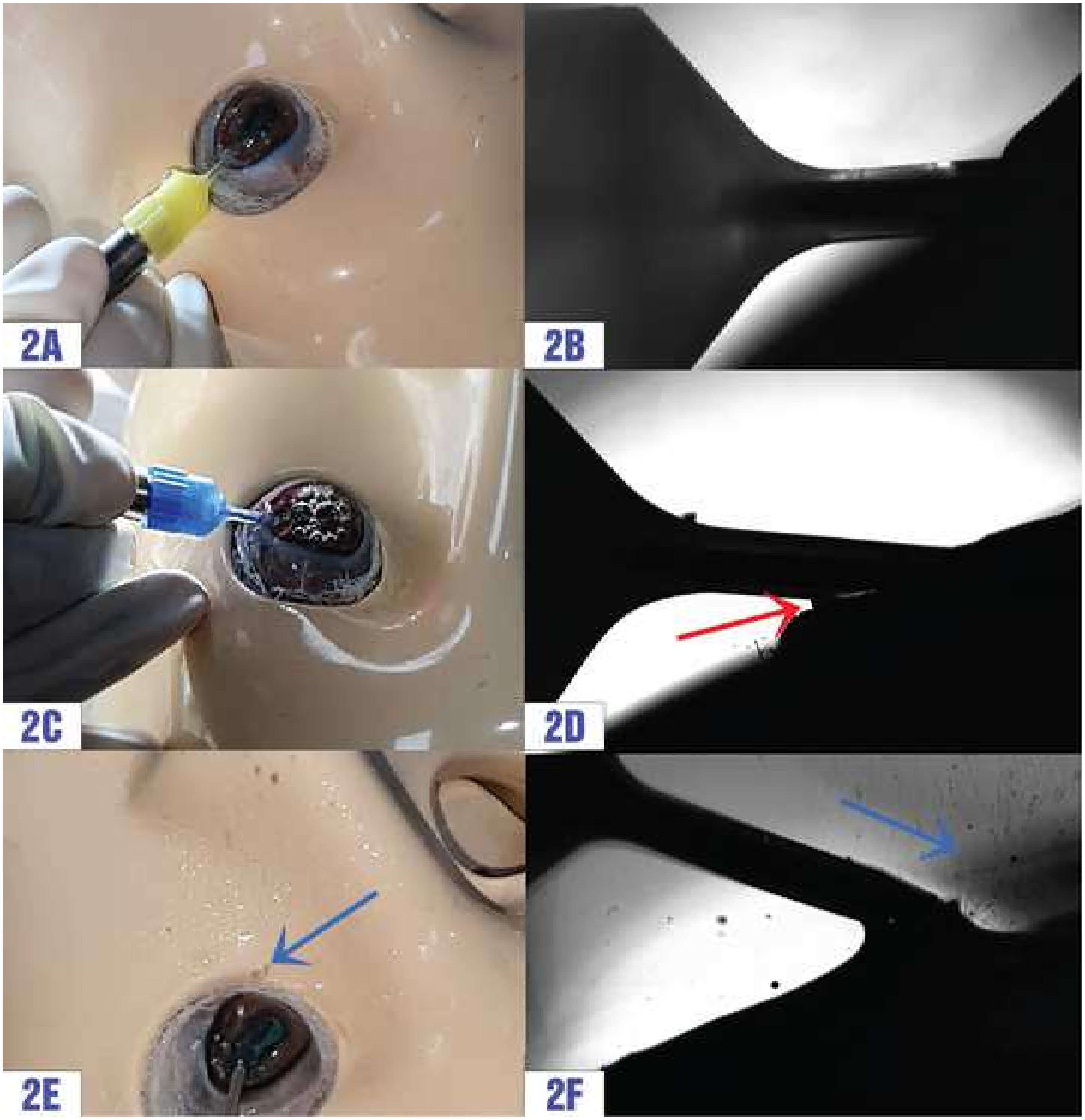
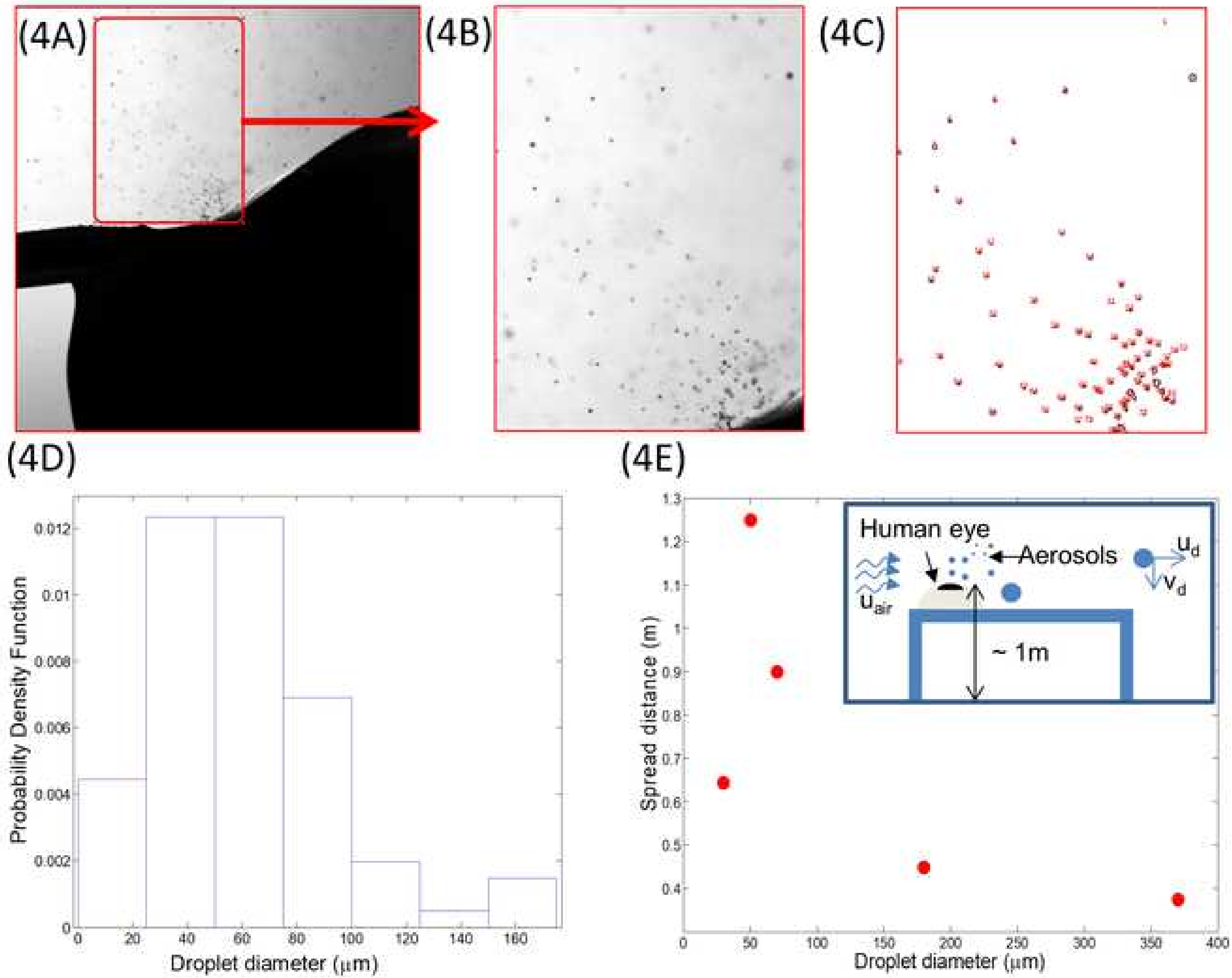


Figure 3

Click here to access/download;Figure;FIGURE 3.tif

Figure 4



(4A)
(4B)
(4C)
(4D)
Probability Density Function
0.012
0.01
0.008
0.006
0.004
0.002
0
0 20 40 60 80 100 120 140 160
Droplet diameter (μm)
(4E)
Spread distance (m)
1.3 1.2 1.1 1 0.9 0.8 0.7 0.6 0.5 0.4
0 50 100 150 200 250 300 350 400
Droplet diameter (μm)
Human eye
Aerosols
u_d
v_d
u_{air}
~ 1m