Original Article

Decoding fluid droplet generation during phacoemulsification and pars plana procedures in the COVID-19 era—An experimental study

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Purpose: The purpose of this study is to evaluate fluid droplet spray generation during phacoemulsification (PE), pars plana vitrectomy (PPV), and fragmatome lensectomy (FL) and assess factors affecting these. **Methods:** This is an experimental study. PE through 2.2 and 2.8 mm incisions was performed in six goat eyes and four simulator eyes using both continuous and interrupted ultrasound (U/S). PPV and FL were performed in three goat eyes. Generation of visible fluid droplet spray was analyzed from video recordings through the microscope camera and an external digital camera. Hydroxypropylmethylcellulose (HPMC) was applied over the incision site during PE and FL. **Results:** When PE was performed through both incision sizes, there was no visible fluid droplet spray if the phaco tip was centered in the incision, without sleeve compression. When there was phaco tip movement with the phaco sleeve sandwiched between the tip and the incision wall, there was visible fluid droplet spray generation. It was more difficult to induce fluid droplet spray with 2.8 mm incision, and spray was lesser with interrupted U/S. During PPV, there was no droplet spray. During FL, fluid droplet spray was only seen when U/S was delivered with the fragmatome tip close to the sclerotomy. HPMC impeded droplet spray. **Conclusion:** Fluid droplet generation during PE can be minimized to a large extent by keeping the phaco tip centered within the incision, avoiding sleeve compression. Smaller incision and continuous U/S were more prone to droplet generation. FL should be performed away from sclerotomy. HPMC over incision is recommended.

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Health-care workers are at constant risk for transmission of various infectious diseases despite safety precautions.[1,2] Bioaerosols are airborne particles of liquid or volatile compounds that contain living organisms or have been released from living organisms. Currently, this is very relevant for ophthalmologists in the context of the novel coronavirus infection (COVID-19). In fact, there are several reports of conjunctivitis in patients with COVID-19 infections[3-5] as well as showing the presence of the virus in conjunctival swabs or tears.[4-6] On the other hand, there are studies which refute the presence of the virus in tears.[7] Airborne transmission may be possible in specific settings where intraocular procedures or support treatments that generate aerosols are performed (Scientific Brief by the World Health Organization, March 2020). In particular, phacoemulsification (PE) and vitreoretinal surgery have been under the scanner due to the potential for aerosol generation owing to the ultrasonic vibrations at the PE tip and oscillatory movements of the vitrectomy probe.

Although there has been much speculation about generation of aerosol and droplet sprays during intraocular surgery, to the best of our knowledge there is no published literature regarding the presence, extent of, and causative factors of the fluid droplet spray generated during surgery. Since this can directly impact the health of the ophthalmologist and support staff, as well as help define working guidelines and preferred practice patterns, we decided to undertake this experimental study in order to evaluate fluid droplet spray during intraocular surgeries.

Methods

This experimental study was aimed at studying the generation of fluid droplet spray and factors affecting them during PE, pars plana vitrectomy (PPV), and fragmatome lensectomy (FL). The Ethics Committee of the hospital approved the study. Freshly enucleated goat eyes obtained from a local abattoir were used. PE was performed in six eyes, whereas pars plana procedures were performed in three eyes. Additionally, PE was also performed in four simulator eyes (Phaco-I, Madhu Instruments, India). The Institutional Ethics Committee had approved the study, and the date of approval of the study was: 9th May 2020.

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Surgical technique—Goat eyes

Phacoemulsification

The goat eyes were fixed on a thermocol block. A single surgeon performed all the surgeries on the Centurion® Vision System (Alcon Laboratories, USA). A limbal incision was made in all eyes, the incision being 2.2 mm in three eyes and 2.8 mm in three eyes. An intrepid knife (Alcon Laboratories, USA) was used to create the 2.2-mm single plane corneal incision. An intrepid balanced tip was used with an Ultrasleeve® (Alcon Laboratories, USA) to perform emulsification. For the 2.8-mm incision, a bi-beveled knife (Alcon Laboratories, USA) was used and the same phaco tip was used with a Nanosleeve. Torsional ultrasound (U/S) was used in two modes: continuous mode and interrupted mode (burst mode) in each eye. In order to enhance visualization of droplets, the balanced salt solution (BSS) was stained with 5 ml of red ink by injecting it into the BSS pouch prior to priming the cassette. The phaco tip was inserted into the anterior chamber and the footpedal was pressed into position 3 to activate ultrasound. U/S energy was applied continuously for 1 min at a time. The phaco tip was intentionally moved in all directions while the energy was being delivered, in order to understand relation of fluid droplet and spray generation relative to the orientation of the tip/sleeve and incision. Standardized U/S and fluidic parameters were used [Table 1]. Dispersive ophthalmic viscosurgical device (OVD, hydroxypropylmethylcelluose [HPMC] 1%) was injected over the wound during energy delivery to observe its effects on droplet generation.

Pars plana procedures

PPV and FL were performed in three goat eyes using a venturi-based vitrectomy system (DORC Associate, DORC, the Netherlands). In addition to use the red ink to stain the BSS, these eyes were injected with 0.5 cm^3 of red ink into the vitreous. An infusion line was introduced through the pars plana. A valved trocar was used to enter the eye 3.5 mm from the limbus. Thereafter, the vitrectomy probe was introduced into the eye and vitrectomy was activated. The surgeon performed vitrectomy for 1 min continuously varying the vitrectomy cut rate from 2500 to 6000 cuts/min and vacuum of 200 mmHg. The vitrector was intentionally moved in all directions within the vitreous cavity, as well as in and out of the valved trocar to various degrees. Subsequently, the trocar was removed and a 0.9-mm bi-beveled MVR knife was used to enlarge the sclerotomy for the 20-ga fragmatome. The fragmatome was then introduced into the vitreous cavity and lensectomy was simulated for 1 min at 10%, 20%, and 30% U/S power, 200 mmHg suction, and infusion pressure of 60 mmHg. The fragmatome was also moved in various directions similar to the vitrector. HPMC 1% was injected over the sclerotomy during energy delivery to observe its effects on aerosol and droplet generation.

Table 1: Ultrasound (U/S) and Fluidic parameters used during phacoemulsification in goat eyes and Simulator eyes

	Goat Eyes (2.2mm incision and 2.8 mm incision) + Simulator Eyes (2.8mm opening)
Torsional U/S preset amplitude – Continuous Mode	60%
Torsional U/S preset amplitude – Burst Mode	60% (On time 300ms, Off time 50ms)
Preset intraocular pressure (IOP, mmHg)	50
Aspiration Flow Rate (cc/min)	25

Surgical technique—Simulator eyes

The phaco tip was used with the Nanosleeve since the eye already has a 2.8-mm rounded port for entry of the phaco probe. Once the phaco tip entered the eye, ultrasound energy was activated for 1 min continuously. In these eyes, 2.5 ml of sodium fluorescein dye was injected into the BSS pouch. Following PE on the simulator eyes, the Matiz head which was used to fixate these was examined under external ultraviolet light in order to detect presence of and extent of fluid droplet spray around the surgical site [Fig. 1].

Recording and analyzing droplet and fluid splatter

A Sony Alpha 7SII ultra-high-resolution digital single lens reflex (DSLR) camera mounted on the beam-splitter of the surgical microscope using an appropriate video adapter tube was used to record the surgical video. Additionally, another ultra-high resolution DSLR with a reverse mounted prime lens was placed on a tripod stand to record a magnified side view of the procedures [Fig. 1c]. For the simulator eyes, the surgical microscope light was switched off and an external ultraviolet light source was used to illuminate the entire surgical field [Fig. 1].

The recorded videos were then reviewed to detect fluid droplets and spray generation, as well as to understand the relation between ultrasound/cutter settings and orientation of the tip/sleeve relative to the incision that led to maximum fluid spray and aerosol generation. The Matiz head was photographed following surgery to evaluate splatter and spray patterns generated during PE.

Results

Phacoemulsification

Tip/sleeve orientation and splatter

With goat eyes, for both the 2.2-mm and 2.8-mm incision, it was noted that when continuous or interrupted torsional U/S (60% preset amplitude, Table 1) was applied with the phaco tip immobile and well centered within the incision and the anterior chamber, we could not detect any generation of visible spray of fluid droplets at the incision [Online Video 1]. With the 2.2-mm incision, whenever the phaco tip was moved to either end of the incision or was touching the roof, we noted that there was visible contact between the sleeve and the phaco tip due to distortion of the sleeve between the rigid tip and the incision wall [Online Video 2a]. Owing to the semitransparent nature of the Ultrasleeve, it was easy to visualize the contact between tip and sleeve [Online Video 2a]. At this occurrence, we could see generation of visible spray of fluid droplets. The direction of the droplet spray was backward and laterally toward the side where the sleeve was distorted and in contact with the tip. When there was compression of the sleeve at the roof of the incision, the visible spray of fluid droplets was directed upward, toward the operating microscope [Online Video 2b]. With the 2.8-mm incision and the compatible tip-sleeve, it was difficult to induce generation of visible droplet spray even with sideways or upward movement of the phaco tip. The surgeon had to perform extreme movements to induce visible sleeve compression to the point where the phaco tip and the sleeve came into contact and visible droplet spray was generated.

Figure 1: (a) Simulator eye showing extent of fluid droplet spray following emulsification in ultraviolet light, (b) experimental setup for simulator eye with fluorescein stained BSS and ultraviolet light and (c) external digital SLR camera for recording of phacoemulsification and fluid droplet generation

Similar findings were confirmed with the 2.8-mm incision on the simulator eyes. Extreme lateral movement of the phaco probe was required to generate visible fluid droplet spray, which was visualized with ultraviolet light [Online Video 3].

Continuous versus interrupted torsional ultrasound

When U/S energy was applied in the burst mode for 1 min, the amount of droplets spray was found to be lesser than when continuous energy was used with both incision sizes in goat eyes. However, in this study, we did not quantify the amount of fluid droplets generated.

On examination of the Matiz head following surgery in simulator eyes, we found that there were significant amounts of fluorescent droplets seen on the forehead, the brow area, and the nose, spreading in all directions [Fig. 1a]. However, it is important to note here that the Matiz head was not draped at the time of surgery. We found that with instillation of HPMC at the incision site while U/S energy is activated, there was almost complete cessation of the droplet spray [Online Video 4].

PPV and fragmatome application

PPV using 23-ga valved cannula did not result in any visible aerosol or droplet spray generation. This was true for different directional movements and withdrawal or insertion of the vitrectomy probe with cutting on. Higher cut rates did not result in aerosol generation either. Activation of U/S energy during fragmatome use led to the generation of droplet spray akin to that seen with PE, with maximum generation when the fragmatome needle shaft came in firm contact with the sides of the sclerotomy [Online Video 5a and b]. The visible droplet spray was significantly more when the fragmatome needle was partially withdrawn out of the eye so that the tip was in proximity to the sclerotomy. When the needle was introduced well into the vitreous cavity, visible droplet spray generation was minimal. Application of HPMC over the sclerotomy led to the cessation of the droplet spray generation.

Discussion

As ophthalmologists across the globe are resuming their practices, there is concern regarding the potential spread of COVID-19 viral infection via droplet and aerosol generation during ophthalmic surgeries. U/S application at air-fluid interface is known to be a potent generator of aerosol. Since PE and lensectomy using a fragmatome utilize ultrasonic energy, concerns over infection spread seem valid. Rapid oscillatory movements of vitrectomy probes could also potentially generate droplets of intraocular fluid. Often, splatter evaporates, leaving smaller particles called droplet nuclei, which can carry bacteria and viruses and transmit various diseases such as severe acute respiratory syndrome and tuberculosis.[8]

We documented that when PE was performed with either 2.2 or 2.8 mm incisions, with conscious effort to keep the phaco tip in the center of the incision and middle of the anterior chamber, the flow of BSS and the sleeve act as a cushion, preventing transmission of the ultrasonic tip vibrations to the incision and the external environment. Koshy and Dickie[9] studied fluid droplet/aerosol generation during phacovitrectomy in one eye and during PE in a training eye. Using high-speed, slow-motion videography, they documented absence of aerosol during both procedures. Similar to our findings, these authors also postulate that the presence of a sleeve and BSS column act as a damper for the vibrations of the phaco shaft and exposed tip, thereby reducing droplet generation. Another experimental study by Darcy and colleagues[10] has shown profuse fluid droplet spray during PE performed on a corneoscleral rim. In this experimental study, the authors showed that there is continuous and copious generation of fluid droplets at the incision site, and this was found to be greater with a 2.8-mm incision as compared to a 2.2-mm one. This is in direct contrast to our findings. We found increased propensity of generation of fluid droplet spray when applying U/S energy through a 2.2-mm incision compatible tip/sleeve. This was maximally found when the surgeon advertently sandwiched the phaco sleeve between the incision wall and phaco tip, causing restriction of BSS flow and allowing transmission of the ultrasonic vibrations of the tip to the sleeve. It is the vibration of this sleeve and incision wall complex that causes the generation of fluid droplets in that area. These droplet sprays were more when continuous U/S energy was delivered. When the same tip was used with its appropriate sleeve through a 2.8-mm incision, it was more difficult to induce droplet spray. We believe there are two reasons for this—one, the sleeve is thicker, thereby providing more mechanical cushion effect, and two, since there is more space between the sleeve and the tip, the surgeon had to cause extreme, even impractical amounts of lateral or upward stress to cause sandwiching of the sleeve enough to generate visible droplet spray.

Our study results show that during PE, it is vital that surgeons pay attention to every detail of their technique as well as their U/S and fluidic parameters. Surgeons must be conscious of the movement of the tip within the incision. Often, surgeons are focused on the cataractous lens alone, and there maybe inadvertent distortion of the incision due to phaco tip movements, with resultant compression of the sleeve. It is therefore important to employ a technique where lens fragment removal is performed within the center of the eye, minimizing movements needed to chase fragments with the phaco tip. Based on the findings of our study, we recommend the use of optimum and not excessive U/S energy, interrupted delivery of

U/S energy, sufficient vacuum and an aspiration flow rate (AFR) with matching intraocular pressure, or bottle height (BH) to ensure maximum follow ability and reduce chatter. Excessive infusion relative to the AFR can cause the fragments to fly around in the anterior chamber, with resultant chasing maneuvers. Although we used torsional U/S in this study, the learnings from this study are as relevant to longitudinal U/S as well, irrespective of the PE platform being used. In our study, we used torsional U/S with a preset amplitude of 60% because this is closer to the U/S energy setting used by surgeons depending on the density of the nuclear sclerosis. Using 100% U/S amplitude may have had a different impact on fluid droplet generation. However, since this would be not be a very practical U/S setting for most cataracts, we preferred to use 60%.

We used fluorescein dye in simulator eyes in order to better visualize the generation of and extent of fluid droplet spray using U/V light. We found that there was extensive spread of the droplets in all directions. However, we believe that this may not be reproduced exactly in a clinical scenario, since extra effort was used in the study to generate visible droplet spray. Also, the simulator eyes were not draped during the procedure. An additional factor in these simulator eyes was that the incision was not water-tight.

During PPV, we did not see any visible fluid droplet spray. This may be on expected lines as the vitrector probe only has cutting movements at the very tip, which is completely immersed in fluid in a closed space, and the entire shaft of the probe is essentially stationary. However, during lensectomy with a fragmatome, the same principles of PE would apply. Due to the absence of a protective sleeve around the fragmatome needle shaft, significant contact between the shaft and the scleral walls is present and would generate significant fluid droplet spray. This spray was accentuated when the fragmatome needle was withdrawn from the vitreous cavity and its tip brought close to the sclerotomy. Therefore, we recommend that when using a fragmatome, the fragmentation should be done away from the sclerotomy and as posterior as safely possible. Trying to perform floatation of the nucleus anteriorly with perfluorocarbon liquids may have more chances of the tip being closer to the sclerotomy site, and therefore, more droplet generation.

Further, as has been reported by Darcy and colleagues,[10] we also found that instillation of HPMC at the incision site dampens the visible fluid droplet spray in both PE and fragmatome-assisted lensectomy. We believe that the higher molecular weight, cohesiveness, and viscosity of HPMC as compared to BSS dampen vibrations and thereby dampen the spray of fluid droplets. Therefore, it is a good practice to frequently instill HPMC near the incision site and over the tip, especially during U/S energy application.

There are certain limitations of our study. Goat eyes may not exactly replicate the dynamics in human eyes. More importantly, although we could detect spray of fluid droplets, which are typically larger than 50 μm in size, aerosol (defined as a suspension of solid or liquid particles in a gas with a particle size of <50 μm)[11] could not be detected with the current system. However, we believe that paying attention to the technique and U/S as well as fluidic parameters as has been discussed above will have a beneficial effect on potential aerosol generation, if any, during these procedures.

Conclusion

In summary, the results of our experimental study show that there is generation of fluid droplet spray during both PE and FL. However, the droplet generation is highly dependent on technique, and excessive manipulation of the phaco/fragmatome tip in relation to the incision can lead to generation of significant fluid droplet spray and possible aerosols as well. The use of interrupted energy and HPMC can dampen this fluid droplet generation.

The most important question we all are worried about today is how clinically relevant these droplets will be in transmitting COVID 19 infections. Although there is no clearcut answer to this, it needs to be kept in mind that in clinical application, physiological aqueous and vitreous humor are replaced by BSS or OVD in both PE and lensectomy (through preceding total vitrectomy) prior to activating U/S. Additionally, there is no evidence to date of the presence of active viral particles within intraocular fluids. However, based on our study results, we would like to make the following recommendations to surgeons as we start embarking on surgical procedures—pay attention to the orientation of your phaco/fragmatome tip, avoid excessive tip movements within the incision and sleeve compression, prefer interrupted modes of U/S energy delivery along with a judicious combination of AFR and BH. In addition to rigorous protocols before, during, and after surgery to limit transmission of the viral infection, adherence to the above recommendations may minimize fluid droplet generation to a great extent, if not completely eliminate it.

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Conflicts of interest

There are no conflicts of interest.

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