ORIGINAL ARTICLE

Interaction of Perfluoro-n-octane with extracted intraocular foreign bodies

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Abstract

Perfluorocarbon liquid (PFCL) s have been known to facilitate foreign body (FB) removal. Their ability to float the frequently encountered FBs in vitreoretinal practice is unknown. We preserved all intraocular foreign bodies (IOFB) removed by pars plana vitrectomy during 6 months period. All FBs were analyzed and tested with perfluoro-n-octane to assess its usefulness in FB removal. Out of total 25 FBs extracted during the period 20 (80%) were nonmagnetic with size varying from 1.5 to 7.5mm. All FBs sank when placed at saline air interface and only 2 (FBs both nonmagnetic) floated when placed at the saline-PFCL interface. In second set of experiments we were unable to float any FB off the bottom of the test container. Higher specific gravity and larger size limit the usefulness of perfluoro-n-octane for floating and manipulating most commonly-encountered IOFBs. Further work utilizing heavier PFCLs and retinal impact measurements are needed to investigate the possible (cushion effect) protection offered by PFCLs during foreign body removal.

Keywords

intraocular foreign body, Perfluorocarbon liquids, surface forces, ocular trauma.

ntroduction

Perfluorocarbon liquid (PFCL)s have found great tility in managing complex vitreoretinal surgical rocedures like retained lens fragments(2), dislocated ıtraocular lens(3), proliferative vitreoretinopathy(4), ıbretinal and suprachoroidal hemorrhage and giant etinal tears(5). High specific gravity, optical clarity, low iscosity and high interfacial tension are the properties ıat make them extremely popular as third hand.(6) erfluoro-n-octane is particularly favorable PFCL ecause of its high purity, refractive index different from vater (easy visualization) and higher vapor pressure.(6) FCLs have been known to float various materials off ie retina. The materials like intraocular lens and retained ens fragments float because their density is lower than FCL. Previous authors have reported the clinical use f PFCL in facilitating removal of glass intraocular oreign bodies (IOFB).(7) PFCLs are also reported to e effective for removal of intraretinal IOFBs by tamponading retina and minimizing iatrogenic tears formation.(8)

The purpose of our study was to confirm our clinical impression that PFCLs do not facilitate the intraocular manipulation of most IOFBs that we deal with clinically.

Methods and Materials

We preserved all intraocular foreign bodies (IOFB) removed through pars plana during 6 months period from Jan 2004 to June 2004. Foreign Bodies (FB) were preserved in a glass vial containing 2% methylcellulose to prevent corrosion. All FBs were analyzed and tested. First a permanent magnet was used to check if they are magnetic (and hence metallic) and then size and specific gravity of all FBs was measured. The largest dimension in mm was taken as the size and specific gravity was measured using Archimedes' Principle as used by Sudhalkar *et al.* (9) Each IOFB was weighed in air (Wa) and water (Ww) and specific gravity was then calculated

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using formula Wa/ (Wa-Ww).(10) All IOFBs were washed with balanced salt solution (BSS) to remove 2% methylcellulose before testing. PFCLs can facilitate FB removal either by floating the FB off the retina or by acting as a cushion and thus preventing retinal injury in case FB drops while removing. So we decided to simulate these two clinical situations during 2 sets of experiments. Testing was done in a glass test tube and a glass vial. Each FB was placed at saline-air and saline-PFCL interfaces in a glass test tube filled with 2 cc of perfluoro-n-octane (PF-OCTANE, VITREO LABS 3109, ISELIN-08830, USA) and 1 cc of BSS to determine its buoyancy. Second set of experiments were performed with a glass vial containing 2 cc of BSS and a FB placed at the bottom. Perfluoro-n-octane in 2 ml syringe with bent 23 G needle was injected underneath each of the FBs one by one to check if they could be floated off the bottom of the vial. Results of both these sets of experiments were recorded for all FBs.

Results

A total of 25 FBs were extracted during the study period. 20 FBs were magnetic and 5 were non magnetic. All non magnetic FBs were pieces of stone. Size of FBs ranged from 1.5mm to 7.5mm. Specific gravity of magnetic FBs ranged from 7.4 to 7.9 and of non magnetic FBs from 2.9 to 3.6. Table 1 lists the magnetic property, size and specific gravity of extracted FBs. During first set of experiments all FBs sank when placed at saline-air interface and only 2 nonmagnetic FBs floated when placed at the saline-PFCL interface. In the second set of experiments we were unable to float any FB off the bottom of the glass vial.

Cushion effect: To know the difference in velocity retardation offered by PFCL (specific gravity, 1.76) as compared to the saline (specific gravity, 1.00) a theoretical model of a magnetic FB falling from the sclerotomy site onto the retina was devised. To simplify the calculations FB size used was 3×2×1 mm (close to average size of FBs we extracted) with mass of 45mg (Table 2). The distance traveled was taken as 20 mm. When a FB falls freely in a fluid, gravitational and buoyant forces act against each other, with buoyant force resisting the free fall. Another force known as drag force which depends on viscosity of the fluid also favors the buoyant force in opposing the downward movement. A series of mathematical equations were utilized to calculate the velocity of given FB falling through saline and PFCL (Table 3).11 We found that the velocities attained by the given FB (dimensions; 3*2*1mm) on reaching the retina after traveling through 20 mm in water and PFCL to be 0.55 m/s and 0.388 m/s respectively with

Table 1

Properties of Extracted Foreign Bodies

Foreign Body (in order of date of removal)	Magnetic	Size (mm)	Specific Gravity	Foreign Body (in order of date of removal)	Magnetic	Size (mm)	Specific Gravity
1	Yes	3.6	7.6	14	Yes	2.5	7.5
2	Yes	2.7	7.8	15	No	5.7	3.0
3	No	4.1	2.9	16	Yes	3.2	7.7
4*	No	2.5	3.1	17	Yes	2.2	7.5
5	Yes	6.0	7.6	18	Yes	2.8	7.5
6	Yes	5.5	7.4	19	Yes	4.0	7.8
7	Yes	1.5	7.9	20*	No	2.8	3.2
8	No	7.5	3.6	21	Yes	2.7	7.6
9	Yes	3.3	7.4	22	Yes	1.8	7.7
10	Yes	1.9	7.5	23	Yes	2.8	7.8
11	Yes	2.8	7.5	24	Yes	3.5	7.5
12	Yes	4.3	7.7	25	Yes	4.5	7.4
13	Yes	3.9	7.4				

* Foreign Bodies floated

Table 2

GN BODY THROUGH THE FLUID

The equation of moti ... h any fluid is given by the ((1)

$$m\frac{du}{dt} = F_e - F_b - F_d$$

Where

F_e = External Force

F_b = Buoyant Force

F_d = Drag Force

Now the external force is the weight of the body in this case. The buoyant force acting on the body will be given by the weight of the liquid displaced.

(2)

$$F_e = mg$$

$$F_b = \frac{m a_e \rho}{\rho_p} = \frac{m g \rho}{\rho_p}$$

F_b: buoyant force
g: acceleration due to gravity
ρ: density of medium
ρ_p: density of particle

The drag force is given by the following equation - (3)

$$F_d = \frac{C_D A_p v_o^2 \rho}{2}$$

Where

C_D = Drag Coefficient

A_p = Projected area of the particle measured in plane perpendicular to motion of particle

$N_{R,p} = \frac{D_p v_o \rho}{\mu}$ Reynold's Number (μ - viscosity)

Drag force is the force experienced by the particle due to the presence of the fluid there. This is calculated as above

Dp : diameter of the particle

Now for the foreign body given

Dimensions: 1mm*3mm*2.0mm

Now the body is approximated to a spherical body whose diameter is calculated by the following formula. (v and s represent the volume and surface area of the particle respectively)

$$\therefore D_p = \frac{6v_p}{s_p} = \frac{6 \times 1 \times 3 \times 2}{2(1 \times 3 + 3 \times 2 + 2 \times 1)} \cong 1.64mm$$

V_p : volume of particle.
S_p :surface area of the particle

$$A_p = \frac{1}{4}\pi D_p^2 \qquad \rho_p = 7.5g/cc$$

$$= 2.133mm^2$$

$$m = volume \times \rho_p$$

$$= 6 \times 10^{-9} \times 7500kg$$

$$= 4.5 \times 10^{-5}kg$$

mass of the given particle

Substituting values from 2 and 3 in 1 we get: - (4)

$$\frac{du}{dt} = g\frac{\rho_p - \rho}{\rho_p} - \frac{C_D u^2 \rho A_p}{2m}$$

Table 3

Calculating velocities of given FB through Saline and PFCL

Body Falls Through Saline

ıg that T ? 298 K $\rho = 1000 kg / m^3$

ature of the medium assumed to be that of normal ambient temperature that is 298 Kelvin and density is l to be almost equal to that of water.

ting these values into equation 4. we get: - $\frac{du}{dt} = 8.4933 - C_D u^2 (176.08)$

ɔ depends on u $C_D = \frac{24 \mu}{D_s u \rho}$

$= \frac{1.95 \times 10}{u}$

$\frac{du}{dt} = 8.499 - 0.343 u$

ting the value of C_D found above into the differential equation we get the above first order linear equation. ing the above equation we can find the velocity of the body after in the fluid as a function of time. ling with the solution we get: -

(As particle falls in the fluid the velocity of the particle will change with distance traveled, that is the speed with which it falls. This will correlate with time also)

u = velocity of the particle at any instant of time t

$\frac{du}{dt} + 0.343 u = 8.499$

Integr factor $= e^{\int 0.343 dt} = e^{0.343 t}$

$e^{0.343 t} du + 0.343 e^{0.343 t} u dt = 8.499 e^{0.343 t} dt$

$d(e^{0.343 t} u) = 8.499 e^{0.343 t} dt$

$e^{0.343 t} u = 24.78 e^{0.343 t} + c$

ting the initial condition (at t=0. u=0) to get the integration constant. we get

$u = 24.78 \frac{(e^{0.343 t} - 1)}{e^{0.343 t}}$

$u = \frac{dx}{dt}$ where x is the position of the body at any time instant t

$dx = 24.78 \times (1 - e^{-0.343 t}) dt$

$x = 24.78 (t + \frac{e^{-0.343 t}}{0.343}) + c_2$

At start t = 0, x = 0, we get

$x = 24.78 (t + \frac{e^{-0.343 t} - 1}{0.343})$

x is the depth of the particle from the top of the medium in which it starts falling at any instant of time t

=20mm, from the above equation we get t=0.65 sec.

ting this time value into the equation for u (t) we get **u (0.065) = 0.55 m/sec.**

: **Body Falls Through PFCLs** **(Similarly)** **u = 0.388 m/sec.**

29% reduction in velocity offered by PFCL (Table 3).

Discussion

PFCLs are valuable and extremely useful tool for complex vitreoretinal procedures.1 They have simplified the management of giant retinal tears5 and posteriorly dislocated nucleus2 and intraocular lenses.3 Temporary tamponade provided due to their high specific gravity (1.76-2.03) has helped in reattaching retinal detachments with advanced proliferative vitreoretinopathy.4 Their usefulness in facilitating IOFB removal remains to be tested clinically. PFCLs can facilitate FB removal either by floating the FB off the retina or by acting as a cushion and thus preventing retinal injury in case FB drops while removing. Our study tested the clinical usefulness of perfluoro-n-octane in manipulating a series of foreign bodies that had been removed from the eyes of actual patients. Perfluoro-n-octane which is most widely used in our part of world and is the preferred PFCL was tested. We found that most (80%) of the IOFBs seen by us are magnetic iron FBs and their size and high specific gravity limits the role of perfluoro-n-octane in their removal. Investigators have reported the use of PFCL in facilitating the removal of a large glass IOFB.7 They theorized that surface forces rather than buoyancy might explain this phenomenon. In an another experimental study Sudhalkar et al have tested potential FB materials with specific gravity ranging from 1.1-8.7 and varying sizes for there affinity for saline and PFCL.9 PFCL used by them was perfluorotributylamine (specific gravity, 1.94). They concluded that for each material tested there is a critical surface/volume ratio above which specimens floated at the saline-PFCL interface. The higher the specific gravity, smaller is the FB size required for floatation. The maximum size for steel FB which could float was found to be 1.4 mm. As is evident from our study the usual size of IOFBs that we deal with is between 1.5 to 7.5mm and the usefulness of PFCLs in floating them off the retina is limited.

Although we were able to float 2 nonmagnetic FBs by placing them at saline-PFCL interface this property of PFCLs is not clinically useful. IOFB once held with forceps or magnet is lifted off the retina and taken out without any effort to place it on saline-PFCL interface. To further determine the clinical usefulness of PFCLs in manipulating IOFBs we devised a theoretical model of a FB falling onto the retina. A series of mathematical equations were sought for to calculate the difference in velocities of a given FB falling through saline and PFCL. The PFCLs were found to retard the velocity and hence can also be expected to lessen the impact of a falling FB onto the retina. This cushion effect can minimize the retinal injuries sustained in case an IOFB falls during removal.

Although cushion effect seems to be offered by PFCLs the actual verification can only be done in vivo. Series of animal studies are required to elucidate the cushion effect thus offered by PFCLs. Also the actual incidence of FB slipping out of forceps and falling onto the retina or optic disc during removal is expected to be low in experienced hands and with increased usage of rare earth intravitreal magnets.

This study has few limitations. First limitation is the use of lighter PFCL (PF OCTANE). Heavier PFCLs like perfluorotributylamine would have floated more number of FBs. Another limitation of the study is the experiments being performed in vitro only.

We conclude that most IOFBs seen by us are magnetic and are too large and heavy to be facilitated by PFCLs in removing them. Since we were also able to make 2 non magnetic FBs (heavier than PFCL) float on PFCL authors support the theory proposed by Sudhalkar et al9 that for small FBs surface forces (adhesive forces) might be responsible for making them float. Theoretically PFCLs do retard the velocity of a falling FB and may provide cushion effect to retina. Further animal studies with larger variety of IOFBs are warranted to define the role of PFCLs in managing IOFBs.

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