Medical Engineering & Physics 36 (2014) 250–254

Contents lists available at ScienceDirect

Medical Engineering & Physics

journal homepage: www.elsevier.com/locate/medengphy

Technical note

Preliminary measurement of gas concentrations of perfluropropane using an analytical weighing balance

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ARTICLE INFO

Article history:
Received 5 February 2013
Received in revised form 13 June 2013
Accepted 4 August 2013

Keywords:
Perfluropropane
Tamponade
Vitrectomy
Macular hole
Retinal detachment

ABSTRACT

We describe the use of an analytical weighing balance of measurement accuracy 0.00001 g for determination of concentrations of perfluropropane (C_3F_8) gas used in ophthalmic surgical vitrectomy procedures. A range of test eyes corresponding to an eye volume of 6.1 ml were constructed using 27 gauge needle exit ducts and separately 20 gauge (straight) and 23 gauge (angled) entrance ports. This method allowed determination of concentration levels in the sample preparation syringe and also levels in test eyes. It was determined that a key factor influencing gas concentrations accuracy related to the method of gas fill and the value of dead space of the gas preparation/delivery system and with a significant contribution arising from the use of the particle filter. The weighing balance technique was identified as an appropriate technique for estimation of gas concentrations.

1. Introduction

A wide range of substances have been investigated as a 'tamponade' or 'support' to the eye following removal of vitreous during vitrectomy in ophthalmic surgery. Baino [1] identifies the broad range of functions performed by the vitreous which include circulation of metabolic solutes and nutrients, provision of ability to absorb mechanical shocks, management of oxygen tension and the provision of structural cohesion of anterior and posterior segments of the eye. In this context, currently no available tamponade material meets all of these requirements though currently there is increasing interest in the properties of polymeric hydrogels. Kleinberg [2] in a similar review of vitreous substitutes emphasises the importance of use of effective agents across a wide range of surgical interventions. In addition, Kleinberg [2] identifies the potential of perfluorocarbon liquids for encouraging retinal reattachment though current issues with toxicity restrict their long term use.

The use of suitable gas tamponades provides initially the pressure to maintain the structural integrity of the eye based on diffusion of other gases from the bloodstream into the gas cavity [3] and as the gas eventually diffuses out of the eye it is replaced with aqueous humor. This avoids any long term problems related to biocompatibility of liquid tamponade agents such as silicone oil [4]. The use of such gas tamponades dates from the 1970s [5]. The vision in the treated eye, however, is significantly affected during the period of shrinkage of the entrapped gas bubble. There are also restrictions in terms of air travel where under reduced aircraft cabin pressure, expanding gas bubbles would present risk of retinal ischemia and postoperative blindness [6]. Risks are also associated with use of nitrous oxide with in situ gas bubbles where the nitrous oxide preferentially diffuses into such enclosed cavities and raises their pressure accordingly [6]. Gas tamponades using perfluropropane (C_3F_8) and sulphur hexafluoride (SF_6) have become the preferred tamponade material used during surgery for macular holes [7]. Tan [8] has indicated that air is not as effective a tamponade agent as sulphur hexafluoride for the treatment of retinal detachment. Thompson [9] has demonstrated that the time for bubbles of perfluropropane to decrease to half original size is proportional to the initial value of gas concentration. The performance of perflupropane and sulphur hexafluoride has been found essentially comparable [10] though some advantage is associated with the faster diffusion rate of sulphur hexafluoride to restore visual acuity more rapidly. A key advantage of gas tamponades compared with liquid tamponades is that a single surgical procedure is required.

It is identified, however, important to deliver gas concentrations of perfluropropane and sulphur hexafluoride close to target values to maintain stability in levels of intra-ocular pressure and in particular avoid pressure spikes. The technique described for determining gas concentrations of such gas mixtures using precision weighing balances provides therefore a means of validating associated clinical techniques and procedures. While simulations of gas concentrations in the filled eye volume have been undertaken

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1350-4533/$ – see front matter
http://dx.doi.org/10.1016/j.medengphy.2013.08.001

Table 1
Estimation of uncertainty in C_3F_8 concentrations due to analytical balance measurement resolution/accuracy over a range of balance systems for nominal 50 ml volume (syringe) and 6.1 ml volume (test eye).

Balance description	Measurement resolution (g)	Uncertainty in % C_3F_8 concentration in 50 ml syringe volume	Uncertainty in % C_3F_8 concentration in 6.1 ml test eye volume
2 place	0.01	2.92	23.952
3 place	0.001	0.292	2.3952
4 place	0.0001	0.0292	0.23952
5 place	0.00001	0.00292	0.024

[11], measurements in test eyes provide more direct evidence of suitability of operative techniques.

It was identified that an analytical weighing balance of suitable accuracy could be used to measure the concentrations of perfluropropane used as a gas tamponade for vitreoretinal surgery within University Hospital, Coventry. The basic technique for measurement of gas concentration in the delivery syringe was to determine the mass difference between the syringe containing initially 50 ml air and then filled with a nominal 50 ml of target 16% vol.% of perfluropropane gas mixture.

Table 1 indicates the uncertainty in C_3F_8 gas concentration in the syringe and test eye based on consideration of balance resolution/accuracy effects. This indicates that the '4 place' balance would provide suitable accuracy for determination of syringe concentration based on maximum magnitude of error of 0.1% of gas concentration but not for determination of levels in the test eye, The '5 place' balance would be suitable for both.

2. Method

2.1. Determination of C_3F_8 gas concentrations in injection syringe

Use was made of a gravimetric weighing balance (Mettler Toledo XP205DR) with resolution of 10 μg. Two modes of sample preparation were investigated using the configuration outlined in Fig. 1.

In the 'non flush mode' perfluropropane gas was drawn into an unused empty 50 mm BD Plastipak syringe (ref 300865) through a three way Luer-Lock tap (BD Connecta reference 394601) and 0.2 μm disk filter (Braun PF2000) until around 10 ml of C_3F_8 gas (BOC special gases) was retained in the syringe. The three way tap was then locked in position to seal ports and the assembly detached from the supply line of the C_3F_8 delivery system. A side tap port (labeled 'vent port' in Fig. 1) was opened to air and the excess C_3F_8 gas expelled to retain 8 ml of C_3F_8 in the syringe. Air was then drawn into the syringe to 50 ml and the three way tap was then locked in position to seal ports.

In the 'flush mode' 50 ml of C_3F_8 gas was drawn into the syringe via the gas intake and all the gas was expelled through the vent port and the process repeated twice. C_3F_8 gas was drawn up a third time and the required concentration of C_3F_8 gas was made up in an identical way as the non-flush mode. A new syringe was used to prepare each gas sample for both techniques.

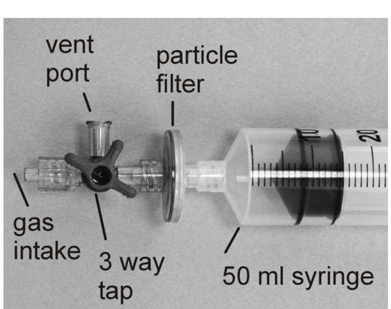

Fig. 1. Gas filling configuration for 'flush' and 'non-flush' techniques.

Previously for both methods the mass of indicated syringe set to 0 ml volume with connection components and of indicated syringe set to 50 ml volume in air with connection components were recorded. The mass of syringe with 8 ml C_3F_8 and 50 ml C_3F_8 was recorded for each relevant technique. Values of local temperature and atmospheric pressure were recorded using calibrated measuring devices. Five separate measurements were made by four individuals for each technique.

It is instructive to consider the errors in gas concentration associated with errors of filling of the syringe. Table 2 indicates the upper bound (Delta_Pos) and lower bound (Delta_neg) on gas percentage concentration considered to arise from errors in positional setting of the syringe plunger when selecting the nominal 8 ml volume and the 50 ml volume when mixing with air with no involvement of dead space. This highlights the need for care with gas filling procedures as a basic requirement of technique.

2.2. Dead space considerations

Eqs. (1)–(4) have been derived to predict the composition of gas mixtures for specific gas preparation techniques. The dead space in the system can be described as two components – V_{ds1} associated with upper section of three way tap and V_{ds2} associated with lower section of three way tap and particle filter. For the 'flush' method, the concentration of C_3F_8 is assumed to be 100%. Where the indicated volume of measured gas in the syringe is $V_{C_3F_8}$ (typically 8 ml) and the final indicated volume of the syringe gas/air mixture as V_{smix} (typically 50 ml) then a predicted percentage gas concentration Pred_C_3F_8(flush) is given by

$$\text{Pred\_C}_3\text{F}_8(\text{flush}) = 100 \times \frac{V_{ds2} + V_{C_3F_8}}{V_{ds2} + V_{smix}} \tag{1}$$

Fig. 2 indicates the estimated concentrations of prepared gas mix with 'flush' method for values of $V_{C_3F_8}$ of 8 ml and V_{smix} of 50 ml as a function of value of dead space volume.

Table 3 indicates the required syringe mix volume with 'flush' method required for a 16% gas concentration as a function of dead space volume V_{ds2} for 8 ml of pure C_3F_8 drawn up to air to indicated 50 ml volume on syringe.

Values of actual gas mixtures prepared were calculated based on the estimated value of dead space in gas preparation system.

Table 2
Indication of the upper and lower bounds on gas concentration percentage considered to arise from errors in positional setting of the syringe plunger when selecting the nominal 8 ml volume of C_3F_8 and the 50 ml volume when mixing with air and with no involvement of dead space.

Magnitude syringe positional error (ml)	Delta_Pos	Delta_Neg
0.1	0.2525	−0.2315
0.2	0.4659	−0.4622
0.3	0.7002	−0.6918
0.4	0.9355	−0.9206
0.5	1.1717	−1.1485