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Accuracy of a peristaltic finger-type infusion pump during hyperbaric oxygen therapy

Hiroshi Dohgomori[1], Kazuhiro Arikawa[1], and Yuichi Kanmura[2]

[1] Division of Emergency Medicine, Kagoshima University Hospital, 8-35-1 Sakuragaoka, Kagoshima 890-8520, Japan
[2] Department of Anesthesiology and Critical Care Medicine, Kagoshima University Faculty of Medicine, Kagoshima, Japan

Abstract
Purpose. To evaluate the accuracy of a peristaltic finger-type pump during hyperbaric oxygen therapy (HBO).
Methods. Using two examples of one type of infusion pump, we evaluated its accuracy at 2 ATA (atmospheres absolute) by measuring the actual volumes pumped at given time points (flow rate) and comparing these data with the corresponding data obtained at 1 ATA.
Results. There was no significant difference in flow rates between 2 and 1 ATA. In terms of accuracy, the present pump was superior to the syringe pump tested in our previous study. Under our conditions, the ambient pressure might have acted equally on the inlet and outlet sides of the infusion line, which may explain the lack of effect of 2 ATA on flow rates. This is not the case with a syringe pump, and the difference in flow-generating mechanisms may help explain the different results obtained in our two studies.
Conclusion. The present type of pump could be used during HBO (at 2 ATA) with the same accuracy as at 1 ATA. Whether the ambient pressure can affect pump input and output (peristaltic-pump infusion line) or only pump output (syringe type) may determine whether accuracy suffers under HBO conditions.

Key words Hyperbaric oxygenation · Infusion pump · Accuracy · Critical care

Introduction

Hyperbaric oxygen (HBO) treatment has been used for many kinds of disease for 40 years, and it is even administered to critically ill patients with severe conditions such as gas gangrene and air embolism [1,2]. When critically ill patients are given HBO treatment, infusions of catecholamines, for example, need to be continuous with the use of infusion pumps during the HBO session itself. Consequently, the accuracy of the pump needs to be examined under hyperbaric conditions. In practice, we use two different types of pumps for continuous infusions: syringe pumps and peristaltic-type infusion pumps. The former uses a syringe and the other an infusion line. Whichever type of pump is used, it is necessary for us to have information about flow-rate accuracy during HBO treatment. Some reports of the accuracy of particular models of infusion pumps have been published [3,4], and some models have been found to be unsuitable under hyperbaric conditions [5]. To our knowledge the Terumo TE-171 peristaltic finger-type pump (Terumo, Tokyo, Japan) has not been tested for accuracy at levels above 1 atmosphere absolute (ATA). We therefore evaluated its accuracy under the conditions actually used in our institution for HBO therapy.

Materials and methods

Methods

We tested two different examples of one type of infusion pump (TE-171, Terumo). We evaluated their accuracy during HBO at 2 ATA. The line fitted to the pump was a special line (TE-EP-304-L-41; Terumo), and the flow rate was set at $10\,ml \cdot h^{-1}$. HBO was performed with a multiplace chamber-type of machine (Nakamura, Tokyo, Japan) by increasing the pressure to 2 ATA using a pattern of pressure changes commonly used by us in HBO therapy (Fig. 1). The pressure was first slowly raised to 2 ATA over a period of 10 min, then maintained at 2 ATA for 60 min, and finally slowly decreased to 1 ATA (in two stages) over the next 15 min (total time, 85 min). As a control, we evaluated the accuracy of the same pumps over a similar time period at 1 ATA. In each experiment, the pump was started 8–25 min

Address correspondence to: H. Dohgomori
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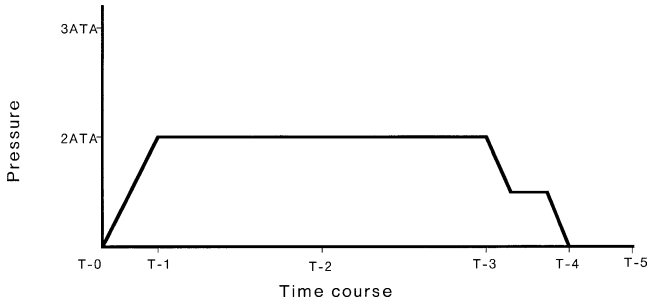

Fig. 1. Protocol used for HBO therapy at 2 ATA. In the HBO treatment protocol, the pressure is raised to 2 ATA, the compression time being 10 min. T-1 is the time point at which compression to the desired ATA level is complete. T-2, T-3, and T-4 are 30 min, 60 min, and 75 min, respectively, after T-1. T-5 is the end point of the experiment. In the control study, we measured the accuracy of the same pumps at a constant 1 ATA over the same period and made measurements at the same time points (T-0 to T-5)

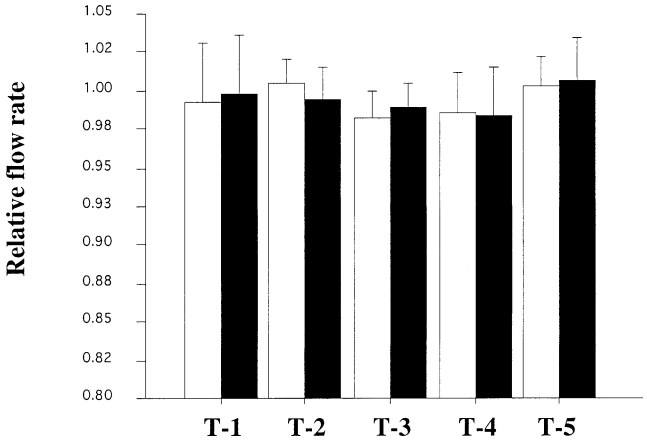

Fig. 2. Relative flow rate showed no significant differences between the two groups. *White bars*, 1 ATA; *black bars*, 2 ATA

(premeasurement period) before the measurement period itself. The premeasurement period varied among the experiments, because we performed the study during the course of our daily treatment of patients, and the start time for each HBO treatment could not be predicted exactly.

Measurements and calculations

We measured volume using glass volumetric-measuring cylinders (Yamaguchi Riken, Fukuoka, Japan), as described previously [1]. The normal saline from the pump was infused via the line into the cylinder through a side-tube near the base. The cylinder was inscribed with a scale with 0.25-ml divisions. Using these devices, volume measurements were made at five time points (see Fig. 1): T-1 10 min after saline collection was started (T = 0), T-2 30 min after T-1, T-3 30 min after T-2, T-4 15 min after T-3, and T-5 15 min after T-4.

For each group (2 or 1 ATA), the volume infused in a given time (flow rate) was expressed relative to the nominal volume expected from the pump setting by the equation.

Relative flow rate = (Volume at T_{aft} − Volume at T_{pre})/Nominal volume during the same time

where T_{aft} is the time point at which the particular volume measurement was made, and T_{pre} is the preceding time point.

Statistical analysis

All statistical calculations were performed using Statview 5 software for Apple Macintosh computers, Means and standard deviations were determined. Inter- and intragroup differences were analyzed by the Bonferroni/Dunn test for multiple comparisons when any significance was seen in a repeated-measures analysis of variance. Differences in the lengths of the pre-measurement periods were analyzed by an unpaired *t*-test. *P* values less than 0.05 were considered significant.

Power analysis

In our previous study [3], we obtained an SD of up to 3% in our analysis at 1.0 ATA. Further, we showed that HBO caused a change in flow rates of up to about 5%. With these data in mind, and setting the probability of a type 1 error at 0.05 and that of a type 2 error at 0.8, we used the same conditions and calculated that the smallest number of experiments required for the present evaluation was 18.

Results

There was no sudden stopping and no apparent sudden increase in the velocity of pumping due to the change in ATA; nor was there any instance of fire in the chamber. The number of experiments performed was 18 at 1 ATA and 20 at 2 ATA. The premeasurement period was 12.0 ± 5.3 min in the 1 ATA group and 15.0 ± 6.1 min in the 2 ATA group (difference not significant; $P = 0.132$, unpaired *t*-test).

Figure 2 shows the time-related patterns of relative flow rate for the two different ambient pressures. In our comparison of the two different ATA levels, we found no significant differences between the two groups.

Discussion

In critically ill patients, the use of pumps (syringe or peristaltic types) is necessary even during HBO sessions [6]. With advances in medical technology, pumps now have a high degree of accuracy, with errors in flow rate usually within a few percentage points. The pump we tested in the present study (Terumo type TE-171) has this degree of accuracy (under normal atmospheric pressure). However, under some circumstances pumps may show a degree of inaccuracy, even at 1 ATA [7]. We performed the present study because the TE-171 pump had not previously been evaluated at the levels at which HBO is performed.

In normal use, at 1 ATA, the TE-171-pump settings are said by the manufacturer to be valid to within ±4%. As can be seen in Fig. 2, in our experiments we observed deviations from the nominal rate as a pattern of fluctuations. This phenomenon was seen in each group (1 ATA and 2 ATA). In our previous study performed under conditions 2 of ATA with a different type of pump (a syringe pump), we reported significant deviations in flow at T-1 (the end of the compression phase) when the nominal flow rate was $10\,ml{\cdot}h^{-1}$ (the flow rate used in the present study) [3]. In that case, the errors were about ±3.6%. We did not see errors of anything like that magnitude at T-1 in the present study. Indeed, all deviations from the nominal rate (at T-1 to T-5 at either ambient pressure) were within ±1.5% in the present experiments.

The pump used in the present study creates flow by compressing and decompressing the line at five adjacent places in a sequential, wavelike manner, each cycle taking a few seconds. This flow-generating mechanism is different from that used in a syringe pump. In the latter, flow is generated by a motor moving an arm and hence the syringe piston attached to it. One difference inherent in these pumps is that in the type used in the present study, the changes in ATA act directly on both parts of the line (the inlet to and the outlet from the pump). In the case of the syringe pump, we speculate that because the piston of the syringe is fixed to a rigid pump arm, changes in ambient pressure do not affect the syringe piston itself. In a syringe pump, the only place at which ambient pressure can act directly is on the outlet line. Compression of this line could have resulted in the depression of flow rate in the T-1 phase (compression phase) seen in our previous study [3]. However, we cannot be sure whether this explains the differing extends to which the pumps reacted to changes in ambient pressure.

Manufacturers do not necessarily recommend the use of pumps under HBO circumstances. In other reports, sudden cessations in flow were seen, and significant errors in flow have been reported at ATA levels above 1.0 [4]. In the present study, we did not see such sudden cessations or, for that matter, sudden increases in pump speed. Nevertheless, we think that care is needed in using pumps during HBO treatment because of such factors as ambient pressure-induced changes in the resistance of the line. Our recommendation is that all pumps should be tested beforehand under the actual conditions in which they are to be used during HBO treatment.

During HBO treatment, extreme care needs to be taken to avoid fire breaking out in the chamber. When oxygen is being used, electrical devices such as pumps that can generate heat or sparks pose a potential danger. Our conditions involve the use of air and oxygen, and we make sure that the concentration of oxygen is kept below 23% [2]. This point should be borne in mind whenever electrically driven pumps are used during HBO.

One limitation in any study of the present type is the accuracy of the measuring system. The device we used was incised with 0.25-ml divisions, and we used the same measuring system in our previous study [3]. We cannot exclude an influence of the accuracy of the measuring system. However, in the present study, the SD values were quite small at 1 and 2 ATA, and we found no significant differences in flow rates between the two groups, even though the same measuring system allowed us to see such differences in our examination of a syringe pump [3]. Therefore, we think that the measuring system we used is suitable for studies of the present type.

A second limitation is that we tested only one kind of pump under one HBO condition (2 ATA), and we evaluated the accuracy at only one flow rate ($10\,ml{\cdot}h^{-1}$). Use of other flow rates or difference HBO treatment protocols might produce different results, and further study will be necessary if the present type of pump is to be used under conditions different from ours. However, our main aim was to evaluate the pump under the conditions we actually use for HBO therapy, and this we have achieved. Nevertheless, because of the possibility of occasional errors and speed changes, continuous observation during HBO is necessary, even if a given type of pump has shown accuracy under test conditions, because there might be other factors that could affect pump accuracy. These might include the resistance of any needles in the line or that of the lines themselves.

A third limitation is that we did not evaluate the influence of hyperbaric conditions on the pumps over prolonged periods of time. However, we evaluated the pumps over the time periods actually used by us for HBO therapy now and in the foreseeable future. Notwithstanding the above comments about the accuracy of the present type of pump and about the need for testing under the conditions actually to be employed for HBO

therapy, we think that international standards of accuracy are needed now, as previously pointed out [5,8].

In conclusion, we found no significant differences in the infusion rates produced by a peristalic-type pump (TE-171, Terumo) between use during HBO (at 2 ATA) and at 1 ATA. However, strict observation is still advisable during HBO treatment of patients, and we further recommend that whenever the use of such pumps is planned, testing of each individual machine be performed in advance under the conditions to be actually employed during the HBO sessions.

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