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On the Physics of the Infant Feeding Bottle and Middle Ear Sequela

Ear Disease in Infants Can be Associated with Bottle Feeding

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Abstract

Background

When using conventional feeding bottles, negative pressure is generated in the oral cavity as well as in the bottle when fluid is removed by sucking. The negative pressure inside the bottle causes the infant to suck excessively and the intraoral negative pressure may subsequently be transmitted to the middle ear via the eustachian tube.

Methods

In the present study simultaneous pressure recordings were performed in the feeding vessel and the middle ear using three types of feeding bottles.

Results

With conventional non-ventilated and under-ventilated bottles a negative pressure formed while the infant sucked and negative intratympanic pressure was frequently generated.

Conclusions

It is suggested that this sequence of events may lead to secretory otitis and itís accompanying consequences. In contrast, a fully ventilated bottle showed positive pressure throughout the feeding procedure, which is similar to normal breast-feeding, and negative pressure changes were not recorded in the middle ear.

MeSH Headings: Otitis Media, Bottle Feeding, Infant, Infant, Newborn.

Introduction

The incidence and prevalence of otitis media in children has remained very significant over time. Fifty percent of infants develop an ear infection by one year of age and an increased risk of recurrent acute otitis and chronic disease is seen in infants who have an infection in the first year of life.[1] An infection before age one is the highest predictor of future infections. The incidence is higher in males than in females, in whites than blacks, in lower socioeconomic groups, in native Americans and Alaskan natives, and higher in children with cleft palate and other craniofacial anomalies. The incidence is also higher in early spring and winter, as compared to summer and early fall.[2]

There is thus evidence to show that the etiology of otitis media is multifactorial. Individual factors, such as inherited anatomical and immunological traits are important, as well as the local environmental factors such as nursery care of infants. Socioeconomic factors, including poverty with poor nutrition and close living quarters where many persons live in the same house or apartment, can increase the risk for transmission of pathogens.

Although the incidence of otitis is less with breast-feeding than with bottle-feeding[1], the physiological background of this phenomenon and its relationship to infant feeding bottles have not been studied. The relationship of the physics occuring in the feeding bottle and the resulting physiology in the oropharynx and middle ear have yet to be examined. Middle ear pressures resulting from the above bottle physics have not been elicited. One night at 2:00 A.M., the first author tried to soothe a restless infant who had just suffered another long night of colic. When given a meal from a feeding bottle the hungry child sucked eagerly and hard enough to make the nipple, and even the plastic bottle, collapse. The observation of the collapsing bottle inspired some late hour contemplation. Questions were raised such as "What happens inside the child?" "Can this be harmful?" "Can a negative pressure large enough to make the bottle collapse be transmitted to the ears?" "Is there a connection with the frequent attacks of otitis media?"

Methods

Seven infants were tested, 2 boys and 5 girls, all under one year of age. All children were supplied with transmyringeal ventilation tubes because of recurrent otitis media. Infants were studied using two pressure sensing transducers. The first was used for simultaneous monitoring of the pressure formed in the nipple of the bottle, which reflects the pressure in the oropharynx, and the second pressure transducer monitored ear pressure as an infant sucked.

As illustrated in Figure 1, the first pressure sensing transducer was a Pasco CI 6534 Low Pressure Gauge Sensor. This unit was used for evaluation of the vacuum formed in the nipple of the bottle, which equals the intraoral pressure. The second transducer, a Grove-Tek 1900mm - H20 Gauge Sensor, was connected to the external ear canal for evaluating ear pressures.

Three types of bottles were used (Fig 2) in the tests:non-vented, under-vented, and fully vented bottles. A non-vented bottle is simply a solid walled vessel with a nipple held in place by a cap. An under-vented bottle has holes or slits in the flange of the nipple whereby some air may enter the bottle, once enough vacuum has formed. Measurement demonstrated an increase in air content by two to seven fold, (Craig Brown, unpublished data) which is thought may contribute to colic. The introduction of air into the formula also caused the degredation of Vitamin C by 12 % in the first of two studies (Craig Brown, unpublished data). The reaction by which this occurred is an oxydation reaction.

In a fully vented bottle a direct communication between the outside air and the inside of the bottle is accomplished by a straw-type conduit connecting the threads at the nipple cap with a cavity at the bottom of the bottle. Any vacuum is thus eliminated as air is allowed to pass into the bottom of the bottle without contaminating the feeding liquid with air.

For internal nipple pressure measurements the various kinds of bottles were each fitted with 1.6 mm I.D. plastic catheters with an angle-cut end positioned inside the nipple tip. The tubing was connected to the input (liquid end) of a 300ml isolation vessel (air over water). This tubing was purged of all air, and the vessel liquid level was maintained at the same horizontal level as the nipple end. The vessel output (air end) was then connected to the nipple pressure transducer.

Earplugs supplied with 1.6 mm I.D. plastic catheters were used for ear measurements. The seal of the earplug was monitored continuously by observing for abrupt deflections of the recorded curve and zeroing of the digital data plotter, indicating that the seal was lost. Concurrently, visual inspection of the placement of the plug was performed. A Dwyer Instruments, Inc. Model 1211-48 slack tube manometer was used for accurate calibration of both pressure transducers. Data from both sensors was observed and collected simultaneously using a standard IBM type PC running a Windows based data acquisition program. Sampling was accomplished by two A/D converters.

For the ear testing, a fully vented bottle, without any vacuum, was always used for the initiation of feeding so no initial vacuum would be introduced from the bottle into the oropharynx and subsequently into the ear. In a fully vented bottle, inverted during feeding, the pressure at the level of the nipple tip was measured in pilot tests and found to be continuously positive during the entire feeding cycle. The infant then drank from under-vented and un-vented bottles, in that order, so as to minimize any introduction of negative pressure artifact into the oropharynx and thus into the middle ear. Seven infants were tested, 2 boys and 5 girls, all under one year of age. All children were supplied with transmyringeal ventilation tubes because of recurrent otitis media.

Results

With non-vented and under-vented bottles the initial pressure at the nipple was first slightly positive, a finding that was identical to the results found with the fully vented bottles. After a short while, however, when some of the fluid had been sucked out of the bottle, the positive pressure at the level of the nipple was reversed in the non-vented and under-vented bottles and an increasingly negative pressure was generated during the feeding. As the vacuum increased so did the resistance to flow, making the child suck even harder when trying to evacuate the bottle.

In the non-vented and under-vented feeding bottles as liquid was removed by the baby sucking, a significant vacuum was formed. A negative pressure of 41.14" of water (equivalent to -1045 mm H20, -10.25 kPa, or -76.86 mmHg) was generated with the non-vented bottle and a negative pressure of 22.87" water pressure (equivalent to -581 mm H20, -5.70 kPa, or -42.73 mmHg) was noted in the under-vented bottle. The rapidity of the drop is due to the closed volume of the bottle with no venting. In non-vented bottles the vacuum quickly became so significant during feeding that the nipple collapsed. This was especially true at the beginning of the feeding cycle when there was less air in the bottle, resulting in less liquid needing to be evacuated to reach the point where the vacuum was sufficient to cause nipple collapse. A very significant vacuum also formed in under-vented bottles but at a slower rate than with the non-vented bottle. This is due to air slowly entering the bottle through holes or slits in the rim of the nipple and, thus, the downward slope of the negative pressure curve was not as steep. The fully vented bottle started with a positive pressure that slowly decreased to atmospheric pressure. Negative pressure never formed in fully vented bottles.

The graphs in figures 3 and 4 show a direct correlation between the negative pressure formed from sucking on non-vented and under-vented bottles and the pressure in the middle ear. As soon as the vacuum became great enough, the pressure in the middle ear followed the same course with a rapid negative deflection. This indicates a transfer of the negative pressure formed in the oropharynx directly through the eustachian tube into the middle ear. The transfer of negative pressure from the bottle was seen regularly in the infants using under-vented or non-vented bottles.

An upwardly positive middle ear pressure was noted in the infants using the positively vented bottle. The physics present in infant feeding bottles is presented in Figs. 5-8. Evidence of the rapid negative pressure formation in non-vented bottles is seen is Fig 5. A readily observable demonstration of the vacuum present in the under-vented bottle is seen in Fig. 6, as the nipple collapses and air bubbles are entrained into the bottle to replace the forming vacuum, with a graph of the under-vented bottle physiology shown in Fig. 7. The presence of positive pressure in the vented bottle is noted in Fig. 8, with the correlation between the increasingly positive pressure in the middle ear and the increasing bottle pressure noted in Fig. 9.

Discussion

During normal breast feeding breast milk is ejected in repeated small portions when oxytocin stimulates milk release via the myoepithelial cells in the milk glands and ducts. This causes a positive pressure within the gland and there is no negative pressure build up. This study demonstrates that when sucking from a non-vented or under-vented bottle negative pressure is generated in the bottle as well as in the oro-pharynx and, subsequently, in the middle ear.

Physics of the various feeding bottles:

The measurements showed that vacuum formed in most reusable feeding bottles, which are either non-ventilated or under-ventilated through various configurations of holes and slits in the nipple rim or nipple proper. The non-vented bottle is simply a solid walled vessel with a nipple held in place with a cap. The cap holds the enlarged flange end of the nipple (the portion of the nipple in contact with the feeding device) firmly against the top of the bottle forming a tight seal. This arrangement constitutes a solid walled container which does not permit any air entry, resulting in the liquid being held within the feeding vessel by the vacuum which is formed while sucking. Fluid may only be removed by the infant in small amounts by overcoming the stiffness of the wall of the nipple or bottle and collapsing one or the other with a resulting small amount of liquid leaving the bottle. The high negative pressure formed (Fig. 5) at the very onset of feeding is the exact opposite of the positive pressure which occurs during physiological breast feeding.

As the nipple collapses due to the negative pressure in non-vented or under-vented bottles the baby will break its seal at the nipple and swallow air along with liquid into the stomach. When these types of bottles are in the feeding position, the negative pressure in the bottles causes a stream of air bubbles to percolate through the liquid.This occurs either through the nipple hole itself or in between the bottle neck and the flange of the nipple. The collapsed nipple and bubble induction into the feeding liquid are clear indications that a vacuum is present in the feeding bottle (Fig. 6). In extreme cases, babies have been observed to even collapse a plastic bottle with vigorous sucking.

The under-vented feeding bottle is identical with the above closed system except that there are one or more holes or slits in the flange of the nipple. This allows air to be drawn into the feeding vessel once a sufficient vacuum has formed in the bottle (assuming that the hole or slit is not pinched shut by over tightening of the cap, a common problem). The infant must first form a vacuum before air is drawn into the bottle. The negative pressure in this kind of bottle tended to form more gradually than with non-vented bottles (Fig 7).

The fully vented bottle has an open pathway for air leading from the threads between the bottle neck and the nipple collar to an internal reservior which is therefore in communication with ambient air. With fully vented bottles the initial nipple pressure was positive, and the pressure remained positive thoughout the entire emptying of the bottle (Fig 8), which is similar to the positive pressure present in breast feeding. At the end of the meal the internal bottle pressure equalized to the ambient pressure. This arrangement serves the double purpose of preventing development of negative pressure in the feeding bottle, as well as preventing the transfer of this pressure into the oropharynx and subsequently into the ear.

Eustachian tube closing failure:

One of the most important functions of the eustachian tube is to protect the middle ear from pressure fluctuations in the airways. Minor nasopharyngeal pressure variations occur with breathing. High positive nasopharyngeal pressures are caused by Valsalva type maneuvers and nose blowing and significant negative pressures occur commonly on sniffing. These positive and negative pressures can be transmitted to the middle ear. Evacuation of the middle ear cavity during sniffing frequently leads to locking of the eustachian tube. In this case the tube commonly displays a one-way valve characteristic, meaning that one direction of passage through the tube is favored, namely, the “down direction” of passage from the middle ear to the nasopharynx. This has been referred to as “eustachian tube closing failure”[3]. Sniffing as a possible cause of ear disease such as secretory otitis media (SOM), atelectasis, adhesive otitis, and cholesteatoma has been extensively investigated in different study groups.[3-10] In one study, a total of 156 ears in 100 children with persistent SOM was investigated. In 63% of ears (73% of individuals) evacuation of the middle ear took place by the act of sniffing.[3]

Otitis media:

The most frequent condition for which a child sees a physician is otitis media.[11] More than 30 million visits for otitis media transpire annually. Office visits increased by 150 percent between 1975 and 1990 with the greatest increase in the number of visits occuring in children under age two.[13] The average percentage of infants who develop otitis media by one year is 50 percent[14]. By comparison, a survey of 85 mothers using a baby feeding bottle that retained positive pressure during the entire feeding cycle showed an incidence of otitis media of less than 30% (Craig Brown, non published data).

Possible causal relationship between bottle feeding and development of ear disease:

The present study, using simultaneous measurements in the feeding bottle and in the middle ear, showed that negative pressure was generated in non-vented or under-vented standard infant feeding bottles and that the negative pressure was transferred to the middle ear during the feeding process. The formation of negative pressures in the feeding bottle can easily be observed by noting the collapse of the nipple or the percolation of air bubbles through the formula. Middle ear evacuation and the subsequent locking of the eustachian tube, as a result of forceful sucking against the increasing vacuum present in common non-vented and under-vented feeding bottles, was demonstrated by pressure recording. An increasingly positive pressure middle ear pressure curve was noted in those infants feeding from a vented bottle. The positive pressure measurements on the middle ear pressure curves correlated closely to the upward trend of the measurements noted on the fully-vented bottle pressure graphs (Fig.9).

Negative pressure in the middle ear is known to be a precursor to serous otitis. An effusion of fluid can interfere with hearing and lead to delayed speech and cognitive development in younger infants. The negative pressure may also predispose to bacterial otitis media and more severe complications. It has been shown that negative pressure such as that generated by sniffing is involved in the development of permanent retraction type middle ear disease manifested by atelectasis of the tympanic membrane, adhesive otitis, and cholesteatoma.[3,4,5,6,7,8,9,10,15,16,17]

Middle ear evacuation and subsequent locking of the eustachian tube, as a result of the intensified and forceful sucking against the increasing vacuum present in under-vented or non-vented bottles, may also be expected when sucking on pacifiers, toys, thumbs, and similar objects. The common denominator in all of these activities is that a negative pressure is generated in the oral cavity and the vacuum may then be transferred via the eustachian tube to the middle ear.

Conclusion

Simultaneous pressure variations in the middle ear and nipple of the feeding bottle were measured and digitally plotted. The results showed that breast-feeding has additional advantages over other methods of nutrition. When using standard baby feeding bottles that are non-ventilated or under-ventilated through various configurations of holes and slits in the nipple rim or nipple proper, the study clearly shows a direct correlation between the negative pressure in the feeding bottle and negative pressure in the middle ear. A causal relationship between the induced negative intratympanic pressure and development of ear disease is suggested. The negative pressure may lead to development of secretory otitis causing hearing impairment and a risk for delayed speech development. The negative pressure may predispose for purulent otitis media and even contribute to development of irreversible retraction type middle ear disease such as atelectasis, adhesive otitis, and cholesteatoma. In order to more closely simulate physiological breast-feeding, it is necessary to avoid vacuum formation and air bubbles. This may be done by using feeding bottles with continuous positive pressure at the nipple during the entire feeding cycle. The present investigation will be extended, using slightly modified equipment, for studying the details of how the negative oropharyngeal pressure is transmitted to the middle ear.

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Figure legends

Fig.1. Equipment used to digitally record simultaneous ear and bottle pressure measurements.

Fig.2. Construction and mechanics of action for non-vented, under-vented and fully vented bottles.

Fig.3. Pressure graph showing the negative pressure transfer from the oropharynx into the middle ear.

Fig.4. Pressure graph showing the negative pressure transfer from the oropharynx into the middle ear.

Fig.5. Pressure graph showing the rapid induction of negative pressure occuring within a non-vented bottle, which became very significant.

Fig.6. Illustration of the bubble formation and nipple collapse due to the vacuum which forms in non-vented and under-vented bottles.

Fig.7. Pressure graph showing a slower induction of negative pressure occuring in an under-vented bottle, which became significant over time.

Fig.8. Pressure graph showing continuous positive pressure in a fully vented bottle.

Fig. 9. Pressure graph showing the positive pressure transfer from the oropharynx into the middle ear.

Fig 1

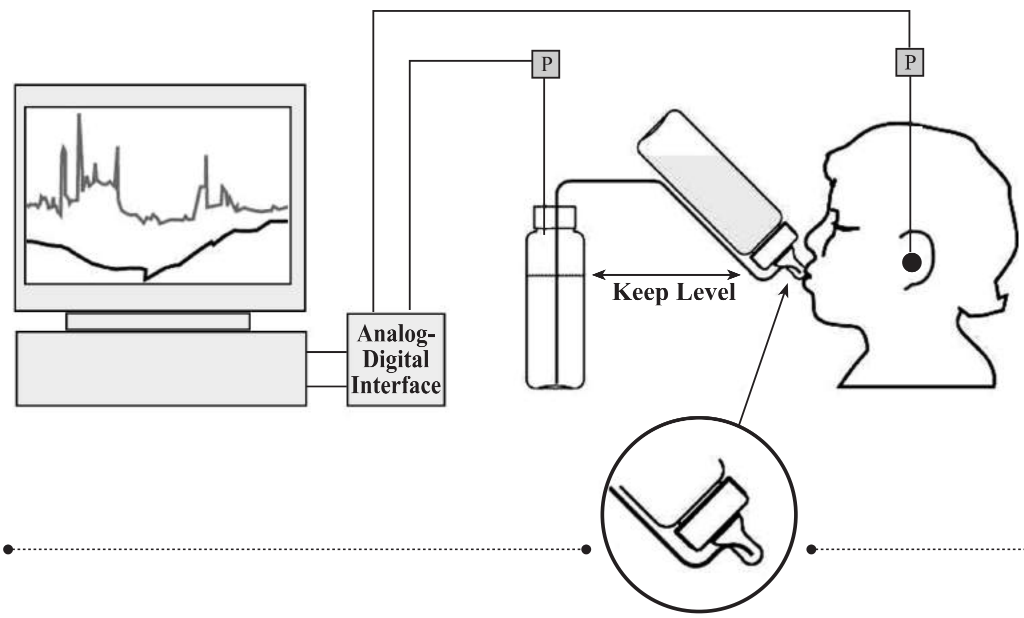

P
P
Analog-
Digital
Interface
Keep Level

Fig 2

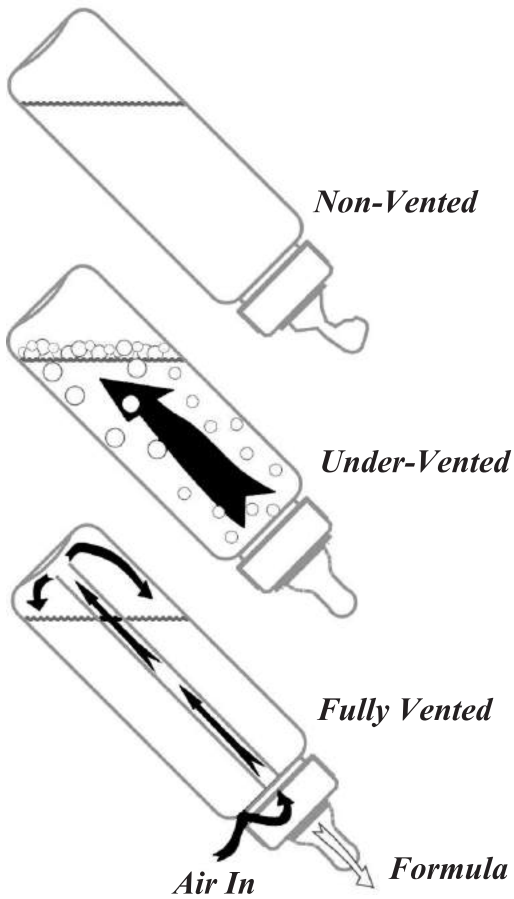

Non-Vented
Under-Vented
Fully Vented
Air In
Formula

Fig 3

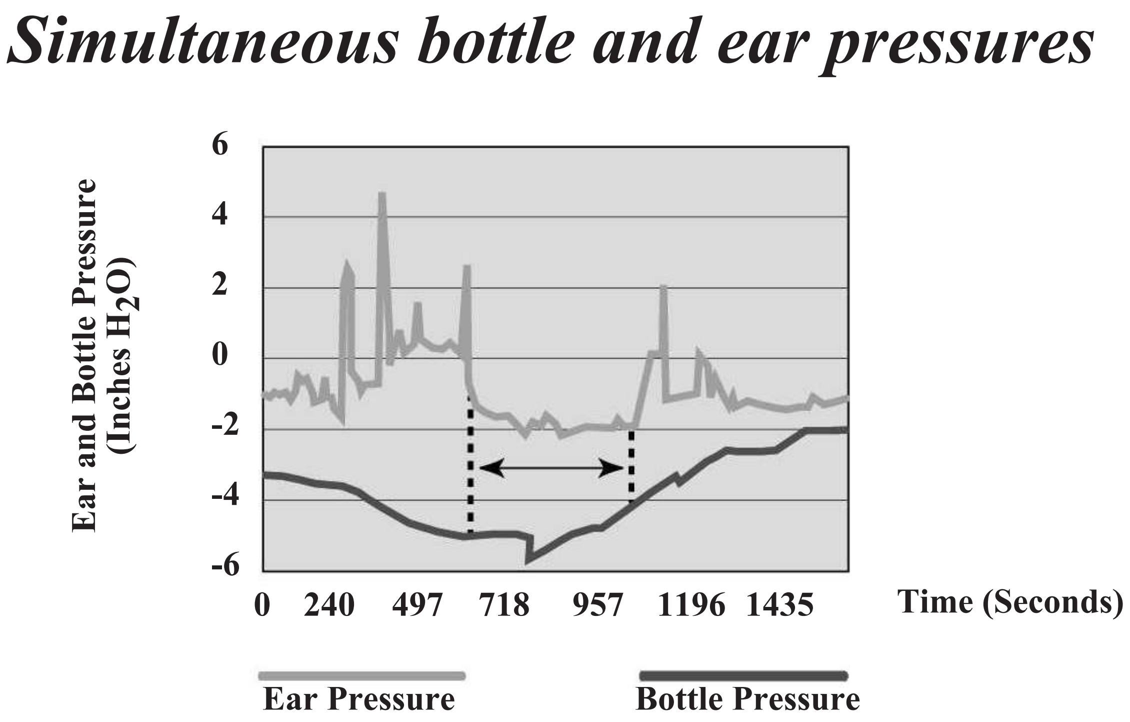

Simultaneous bottle and ear pressures
Ear and Bottle Pressure (Inches H_2O)
6
4
2
0
-2
-4
-6
0 240 497 718 957 1196 1435
Time (Seconds)
Ear Pressure
Bottle Pressure

Fig 4

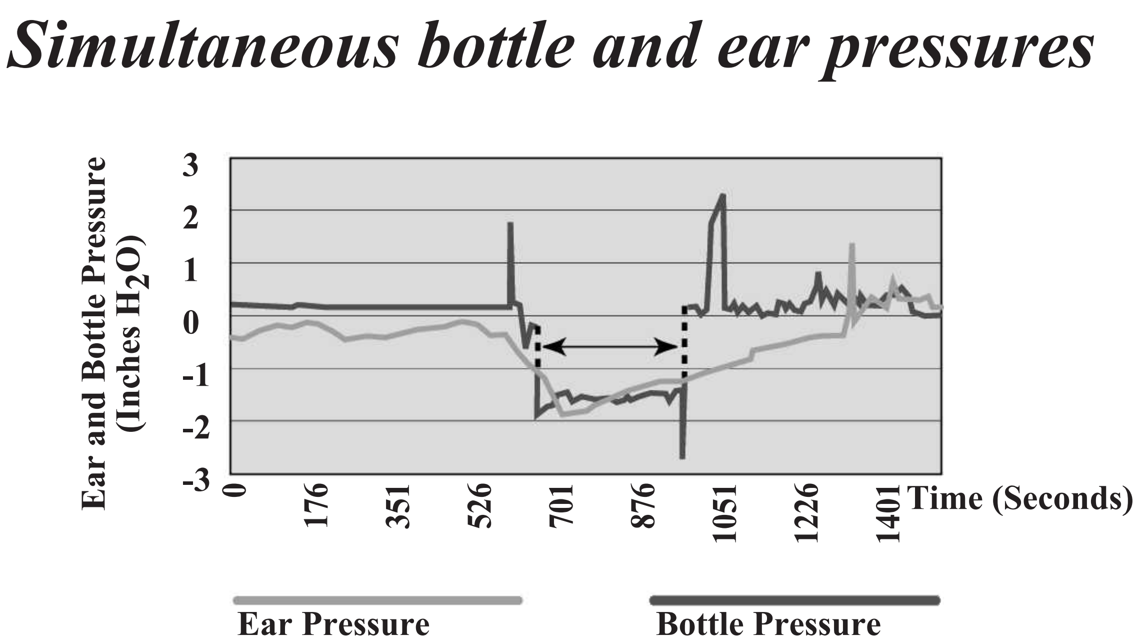

Simultaneous bottle and ear pressures
Ear and Bottle Pressure (Inches H_2O)
3
2
1
0
-1
-2
-3
0 176 351 526 701 876 1051 1226 1401
Time (Seconds)
Ear Pressure
Bottle Pressure

Fig 5

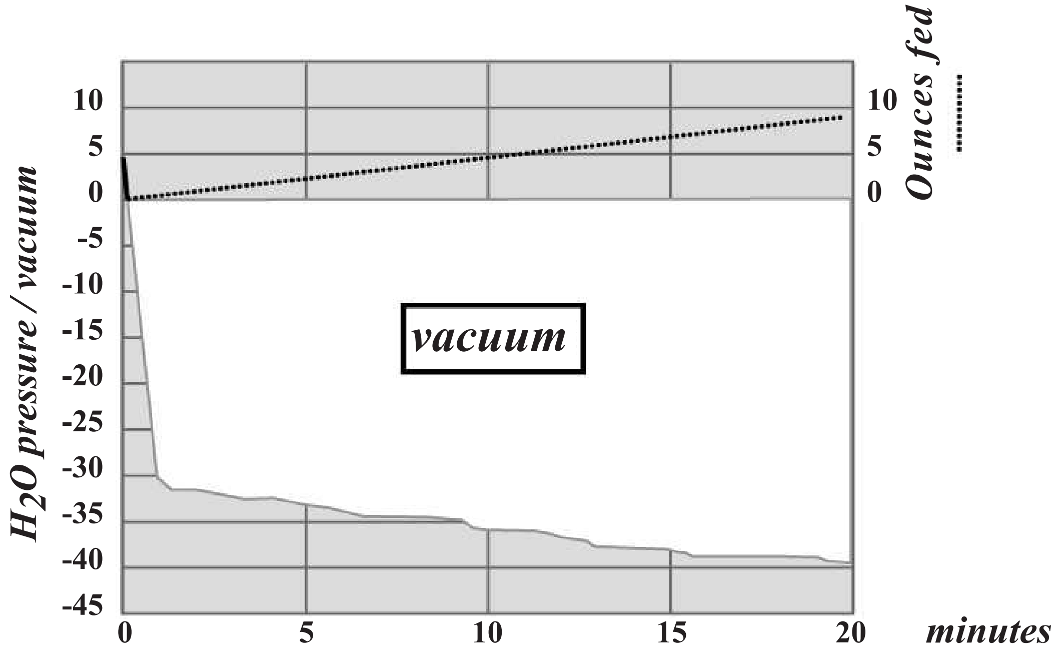
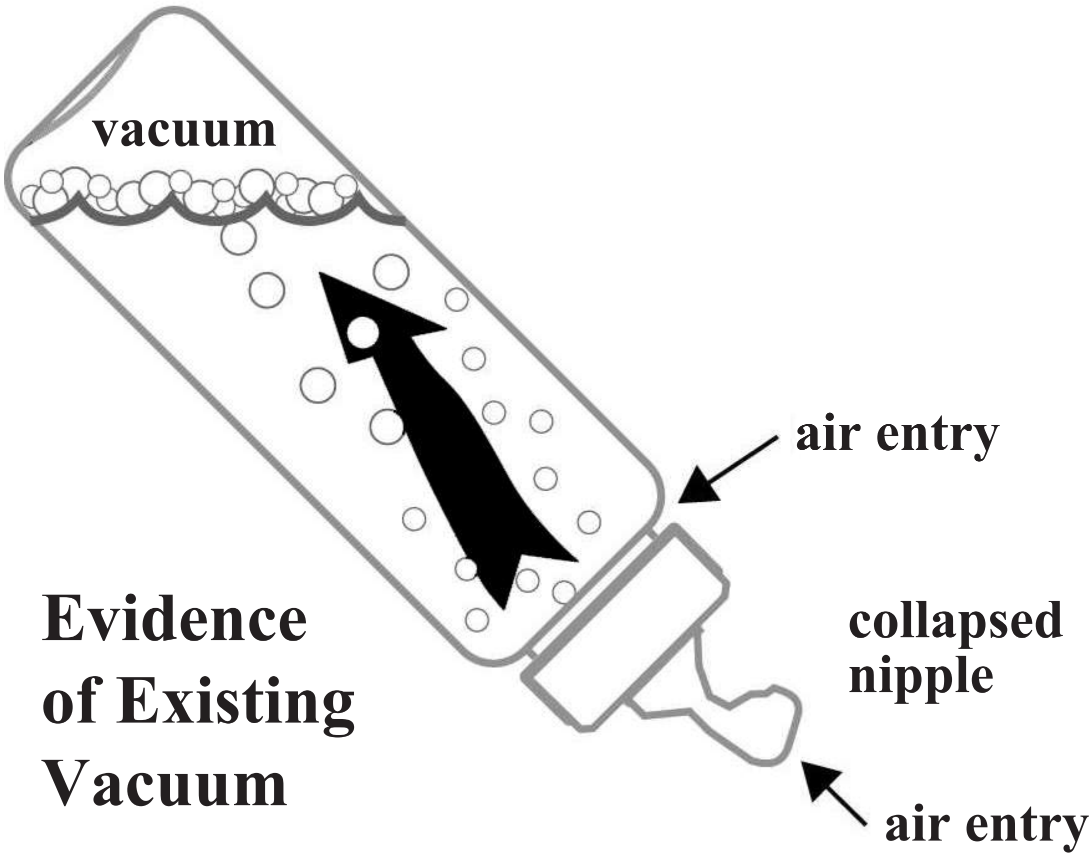
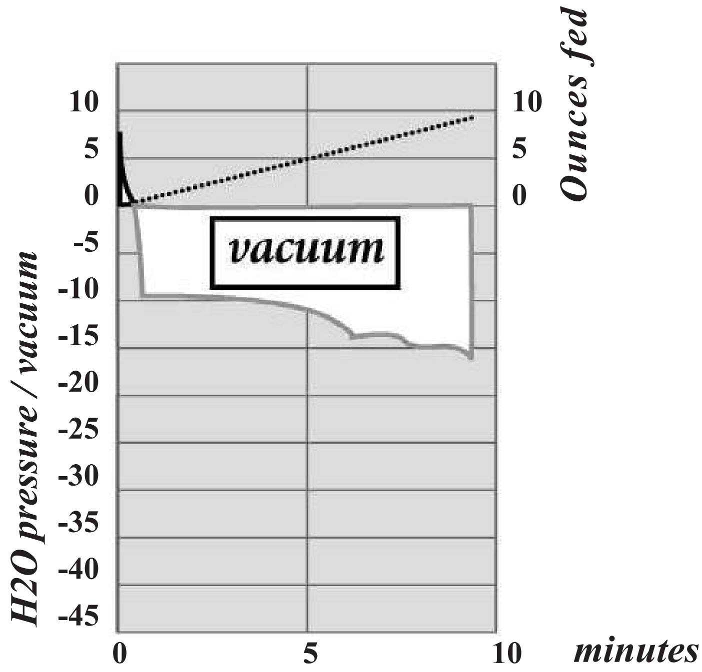


Fig 6



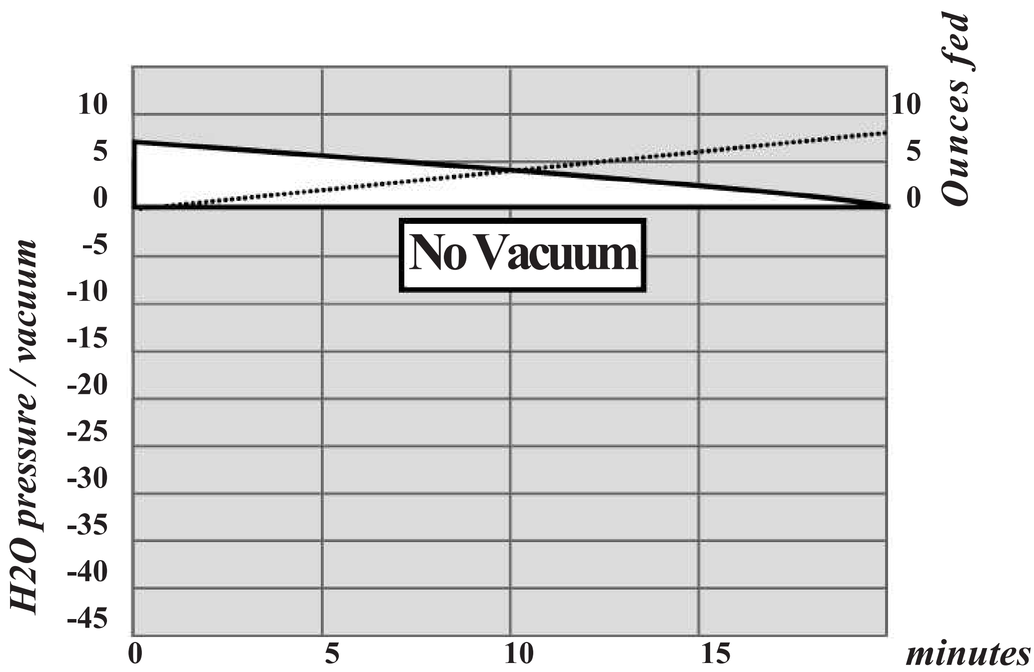
Evidence of Existing Vacuum

Fig 7



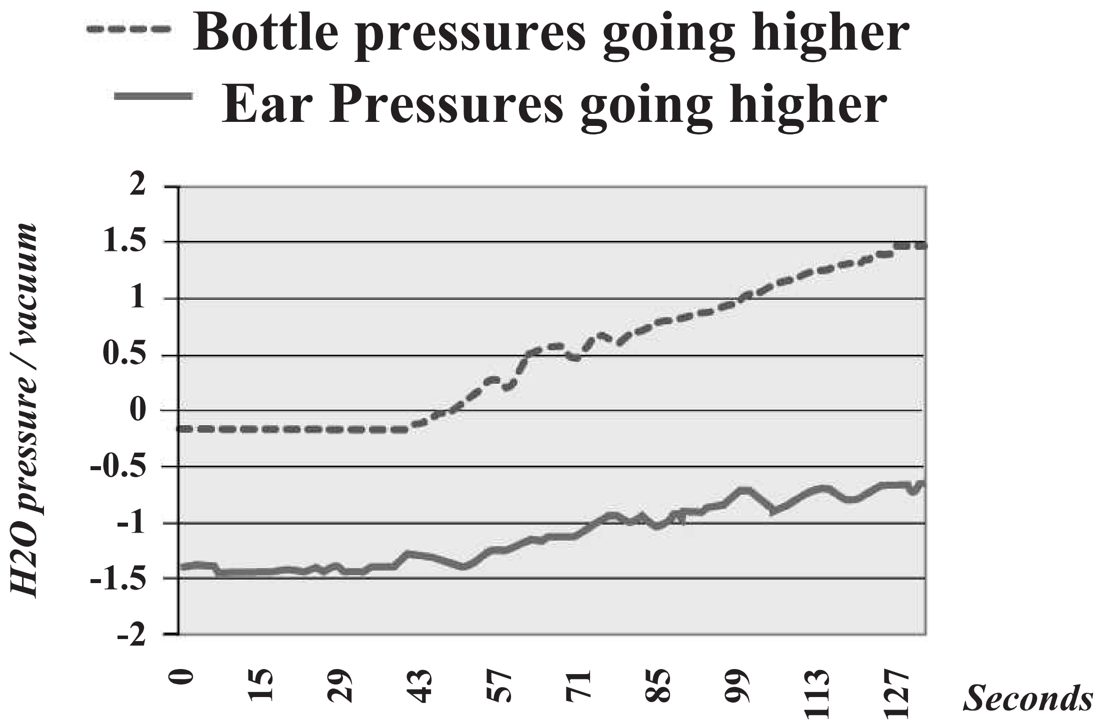
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
H2O pressure / vacuum
vacuum
10
5
0
Ounces fed
0
5
10
minutes

Fig 8



10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
H2O pressure / vacuum
No Vacuum
10
5
0
Ounces fed
0
5
10
15
minutes

Fig 9


Bottle pressures going higher
Ear Pressures going higher
H2O pressure / vacuum
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
15
29
43
57
71
85
99
113
127
Seconds