Passive Flooding Of Paranasal Sinuses And Middle Ears As A Method Of Equalisation In Extreme Breath-hold Diving (vol 45, pg 657, 2011)

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Passive flooding of paranasal sinuses and middle ears as a method of equalisation in extreme breath-hold diving

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ABSTRACT

Breath-hold diving is both a recreational activity, performed by thousands of enthusiasts in Europe, and a high-performance competitive sport. Several 'disciplines' exist, of which the 'no-limits' category is the most spectacular: using a specially designed heavy 'sled,' divers descend to extreme depths on a cable, and then reascend using an inflatable balloon, on a single breath. The current world record for un-assisted descent stands at more than 200 m of depth. Equalising air pressure in the paranasal sinuses and middle-ear cavities is a necessity during descent to avoid barotraumas. However, this requires active insufflations of precious air, which is thus unavailable in the pulmonary system. The authors describe a diver who, by training, is capable of allowing passive flooding of the sinuses and middle ear with (sea) water during descent, by suppressing protective (parasympathetic) reflexes during this process. Using this technique, he performed a series of extreme-depth breath-hold dives in June 2005, descending to 209 m of sea water on one breath of air.

CASE REPORT

Our subject is a 36-year-old physical therapist, who started breath-hold diving (BHD) at the age of 28. During the first 3 years, he used the conventional BHD techniques of equalising rigid air spaces by repeated Valsalva manoeuvres. Then, finding that these techniques were possibly traumatic and required active muscle contraction, he started training in passive equalisation techniques. This involves keeping the nostrils open during the descent, and allowing water to passively enter the nasal cavity into the maxillary sinus ostia and Eustachian tubes as the air volume decreases with depth.

Over the years, he perfected this technique, and now it has become a quite natural BHD behaviour for him, inasmuch as he finds it difficult to switch back to the conventional techniques.

Using this technique, he attained in June 2005, in the course of a few days with increasingly deep BH dives, a new record depth of 209 m, 35 m deeper than the previous record.

Using MRI, we obtained high-resolution TSE (turbo spin echo) images of his sinuses and middle-ear cavities before (figures 1,2) and after (figures 3,4) instilling water through the nostrils. To do this, he simply used room-temperature tap water, from a plastic bottle, poured sequentially into each nostril. By rotating the head in various positions, our subject was able to fill most of his sinuses and middle ears with water, without any noticeable reflex reaction (sneezing, coughing), pain or discomfort.

On the MRI images, water can be clearly seen, not only in the maxillary, ethmoid and sphenoid sinuses, but also in the middle-ear cavity and in the mastoid recess. After the imaging, only part of the water was passively evacuated by raising the head in an upright position; the rest was evacuated progressively over the next few hours.

DISCUSSION

Our subject claims he is able to avoid equalisation manoeuvres during breath-hold dives by allowing water to passively flood his sinuses and middle-ear cavities. To do this, he neither wears a nose clip nor performs any type of equalisation manoeuvre (Frenzel, Valsalva, Toynbee) during descent, except once or twice during the first metres. He then describes a progressive inflow of water through the Eustachian tube, causing him neither pain nor discomfort, and making further equalisation unnecessary. Upon ascent, this water appears to be only partially drained spontaneously: in the course of several hours, more water is evacuated progressively.

Our investigation was aimed at verifying the possibility of passive filling of the paranasal cavities without adverse reactions. Obviously, no MRI can be obtained during the dive. However, the images obtained 'in the dry' show clearly that our subject is capable of inundating these cavities passively with water, without active injection of any kind.

Allowing the cranial cavities to passively fill with water during descent to extreme depths presents several advantages over active equalisation:

- 'Equalising' the cranial cavities (sinuses, middle ear) is necessary to avoid barotrauma of descent, because the volume of these air spaces is reduced as the environmental pressure increases (according to Boyle's Law of Physics: P×V=constant). As the diver descends, he must progressively place more air into these cavities. This air is therefore not available anymore in the lung, and this, in turn, will contribute to the limitation of pulmonary volume decrease—and thus the maximum attainable depth. Indeed, at a depth of 200 m, external pressure is 21 atmospheres absolute, and according to Boyle's Law, the intrathoracic air-filled space should be reduced to one-twentieth of its original volume. In order to increase the amount of pulmonary air before descending, most elite BH divers use a technique of

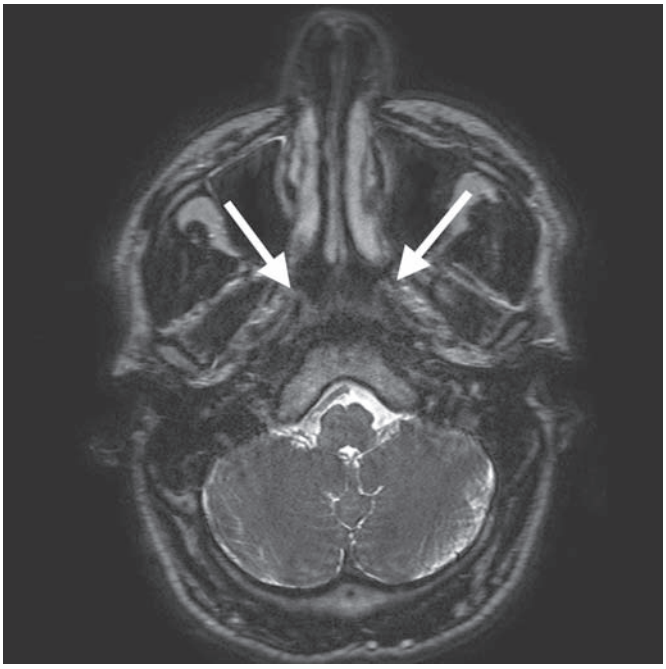

Figure 1 MRI image at the level of the Eustachian tube (arrows) and upper end of maxillary sinuses.

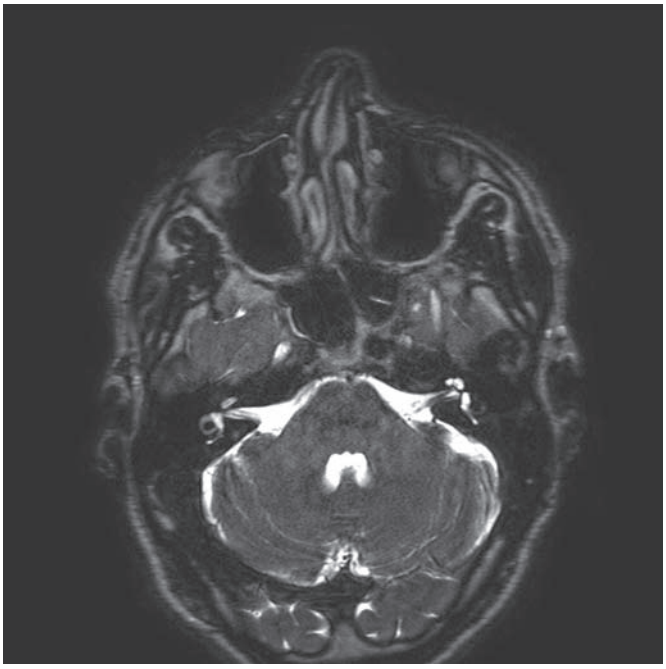

Figure 2 MRI image at the level of the mastoid.

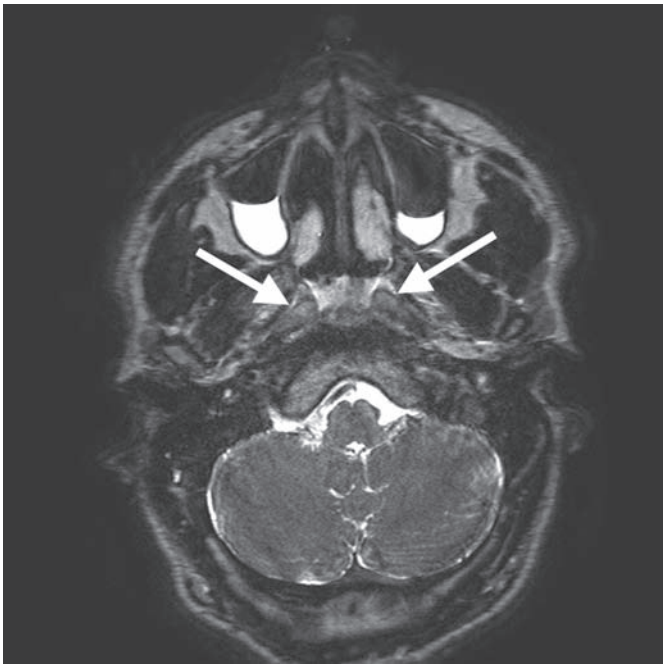

Figure 3 MRI image at the level of the Eustachian tube (arrows) and upper end of maxillary sinuses after voluntary filling with water.

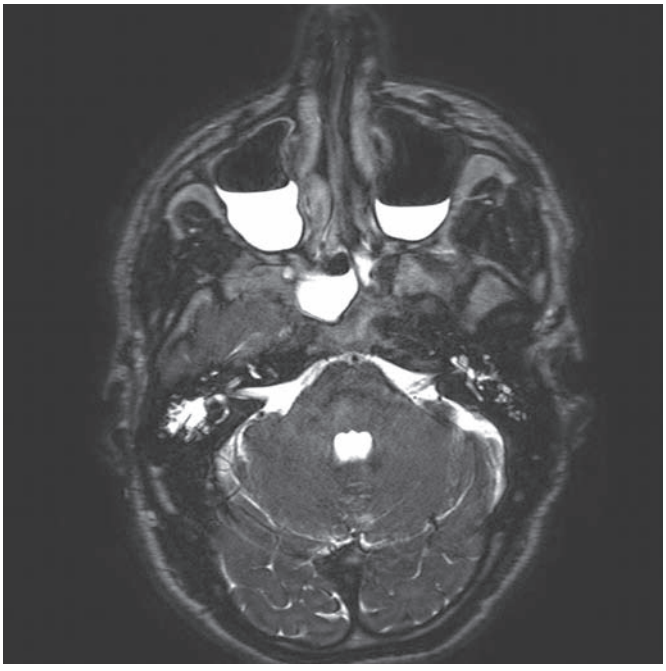

Figure 4 MRI image at the level of the mastoid after filling with water: infiltration of the mastoid recess can be clearly seen.

glossopharyngeal breathing (GPB) to overinflate the lungs and increase their total lung capacity by up to 47%.[1] This technique may present a real risk of serious complications such as pneumomediastinum[2] or even cerebral gas embolism.[3] Our subject has not used GPB since he started training on passive equalisation, and yet has attained extreme depths.

- Avoiding active muscle movements to inflate the paranasal cavities (by performing Toynbee or Frenzel manoeuvres), some economising on oxygen consumption may be obtained. More importantly, it allows the diver to maintain a fully relaxed state during the descent. As the limits of apnoea are preceded by involuntary contractions of the diaphragm ('diaphragmatic spasms'),[4] being able to keep all voluntary muscles in a totally relaxed state from the beginning of the descent on, may represent a significant advantage in prolonging the apnoea time. Furthermore, this may also protect against other adverse affects of extreme BHD, such as pulmonary bleeding.[5] Indeed, whereas almost all elite BH divers consider this as an almost 'normal' side effect of their sport, our subject has completely avoided pulmonary bleeding after BHD

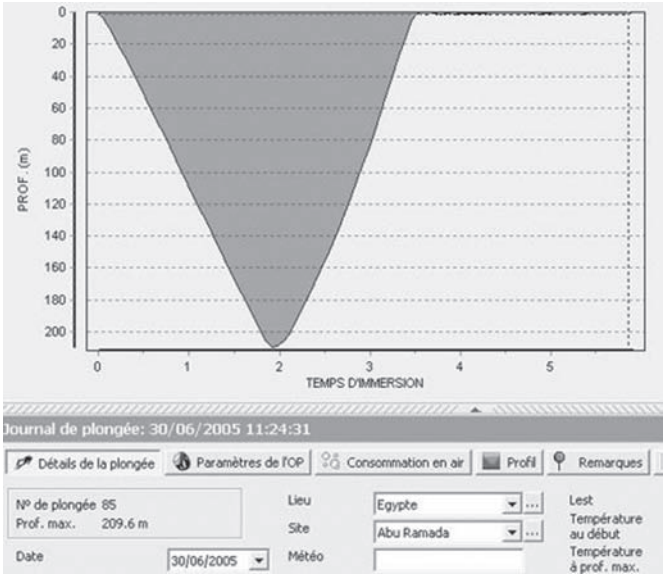

Figure 5 Dive profile (time vs depth) of a 209 msw dive in June 2005.

What is already known on this topic

Equalisation of the middle-ear and sinus cavities is a necessity for divers and aviators in order to cope with the effects of environmental pressure changes on air-filled body cavities. In extreme-depth apnoea diving, the volume of air needed to 'equalise,' and the technique performed to achieve this, may constitute limiting factors in their performance. One recently developed technique claimed by apnoeists is the passive flooding of these cavities with surrounding water.

What this study adds

Using MRI, we demonstrate the filling of sinuses and middle-ear cavities by one diver by simply pouring water in the nose, without the use of injection apparatus. This confirms that it is possible to relax the Eustachian tube orifice sufficiently for water to passively enter the retrotympanic spaces.

training or record attempts since using the 'passive flooding' technique.

- As the diver need not bother about timely equalising, the speed of descent can possibly be higher and uninterrupted, again preventing precocious hypoxia. Indeed, from the profile of his 209 msw dive (figure 5), it can be seen that PM maintained a steady speed of descent of 110 m/min.

Flooding the sinuses and middle ears has possible risks, however.

- Most prominent is the risk of infection. Advanced (deep) training for BHD is only possible in 'open water' (lakes, abandoned quarries, sea), where waters are always colonised by possible pathogens.[6] Since the filling and emptying of the cavities is a passive process, water must remain in the lower portions of the paranasal (maxillary) sinuses for some period after each dive. Upon detailed interrogation, our diver never had any symptoms of sinusitis or middle-ear infection, not even when he began using this technique. Although he is a healthy, sporty person, he never used antibiotics, either preventively or therapeutically.
- Another possible risk is progressive degeneration of the middle-ear mucosa, by repeated rinsing with freshwater or saltwater.[7] This is known to be a cause of external ear osteomas.[8] Saline instillation into the middle-ear cavities of guinea pigs caused inflammation and a decrease in otoacoustic emissions.[9] In our subject, MRI scanning did not reveal any abnormalities in the middle ear, and detailed otolaryngological examination failed to reveal any abnormalities: hearing thresholds and tympanometry were completely normal.

Using this technique requires training. Indeed, the introduction of water in the sinuses and middle ears usually is accompanied by moderate to severe reactions of sneezing and discomfort, sometimes accompanied by pain, as has been reported on different apnoea divers' internet fora. In our subject, the progressive adaptation to these phenomena has been acquired without formal guidance over a number of years of training. He subsequently analysed the techniques used and developed a training method to facilitate this learning process.

In view of the above findings and considerations, we believe this technique to be a feasible method to improve the safety of extreme BHD. Thus far, we have failed to find any negative effects of the use of this passive flooding technique in this diver.

Competing interests PM is the subject of our case report. He occasionally receives financial compensation for conferences on extreme apnoea and on individual and group excellence and achievement. He received and receives sponsorship for the organisation of his apnoeic activities, from companies searching to highlight human achievement.

Provenance and peer review Not commissioned; externally peer reviewed.

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