Ear Barotrauma: What Chamber Operators Should Know (2021)

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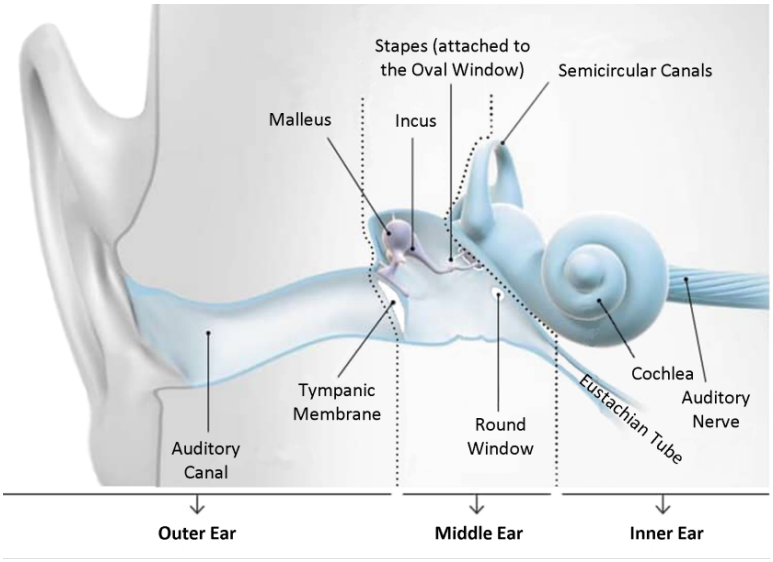
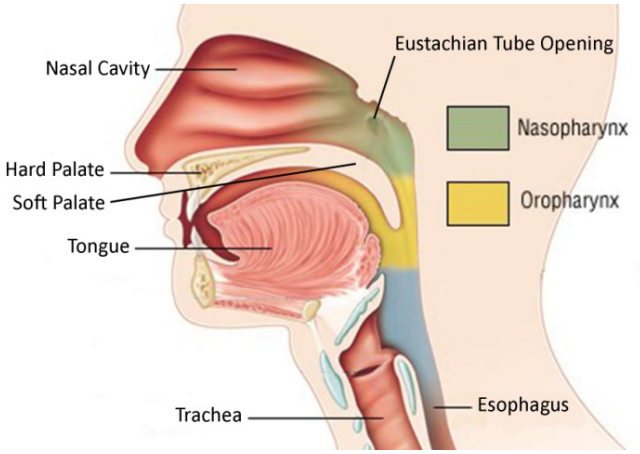
INTRODUCTION

Ear barotrauma (i.e. "ear block", "ear squeeze") is the most common complication of hyperbaric treatment. It occurs when the pressure in the hyperbaric chamber is greater than the pressure in the middle ear. It is prevented by patient assessment, patient education, and the appropriate actions of the chamber operator. The chamber operator has an important role in preventing ear barotrauma in hyperbaric patients.





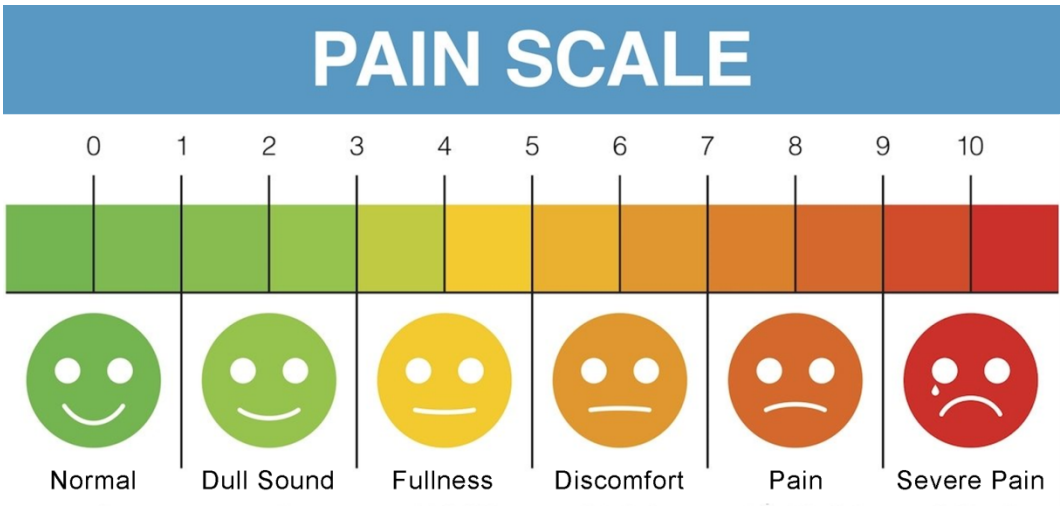
OBJECTIVES

At the completion of this activity, the participant will be able to:

- Describe the anatomy of the middle ear
- Explain the mechanism of ear barotrauma
- Describe 3 techniques to equalize middle ear pressure

ANATOMY OF THE MIDDLE EAR

The middle ear is an air space that separates the external ear canal from the inner ear. The eardrum, called the tympanic membrane (TM), vibrates when sound enters the ear canal. The vibration is transmitted to a series of bones in the middle ear. These bones transmit vibration to another membrane (the oval window) that separates the air-filled middle ear from the fluid-filled inner ear, where sound is sensed in the cochlea. The Eustachian tube is a conduit from the middle ear to the nasopharynx. The nasopharynx is the area behind the nose and above the palate. The left and right Eustachian tubes open into this area. Because of the location of the Eustachian tube openings, the same things that cause nasal congestion (e.g. allergies, upper respiratory infection) can cause swelling around the opening of the Eustachian tubes, making it more difficult to equalize pressure in the middle ear.



WHY DOES BAROTRAUMA OCCUR?

The Eustachian tube openings in the nasopharynx are typically closed, making the middle ear space a sealed container of gas. As the hyperbaric chamber is pressurized, the volume of gas in the middle ear shrinks because of the difference in pressure between the chamber and the middle ear. This creates a relative vacuum in the middle ear which pulls on the TM. As this occurs, the patient will experience a gradual progression of sensations, including: dulling of sound; fullness in the ear (the middle ear actually has less volume at this time, but the best description of the sensation is "fullness"); discomfort; pain; and severe pain. Eventually, the TM will rupture, allowing middle ear pressure to equalize with the chamber. For the purpose of this discussion, let's borrow a standard pain scale, using the same pain score (0-10) but with the descriptors altered to match the expected sensations in the middle ear.

Before the chamber is pressurized, the patient should experience a pain scale rating of zero. As chamber pressure begins to increase, the patient's sensation moves gradually up the scale (from zero, to 1, to 2, etc…). If the patient successfully equalizes pressure in the middle ear, the sensation resets back to zero. Because chamber pressure continues to increase, the patient must repeatedly equalize each time the sensation changes from normal (i.e. the cycle repeats numerous times throughout chamber pressurization). Once treatment pressure is reached and chamber pressure is no longer changing, the patient does not have to equalize pressure any more (i.e. the cycle ends). To avoid ear barotrauma, the patient should stay between zero and 5 at all times. There is no consensus on either the "correct" compression rate or a compression rate that is "too fast". However, the patient experience will move more rapidly from zero toward 10 if the chamber is compressed more rapidly. Slower compression rates give the patient more time to equalize pressure. One clinical trial showed a lower incidence of middle ear barotrauma with a compression rate of 1.3 psi per minute (3 fsw/min) compared to 2.0 psi per minute (4.5 fsw/min).[8]

Patients who are experiencing nasal congestion (from allergies or a cold) or have Eustachian tube dysfunction may have more difficulty equalizing pressure in the middle ear. A patient with nasal congestion may start with a pain scale rating of 1-4 (instead of zero) before entering the chamber; and would likely reach the level of discomfort or pain more quickly. For many patients, one ear is more difficult to equalize than the other. It simply means that one Eustachian tube is less cooperative than the other. It also means that a patient can have a barotrauma to one ear and not the other; or have different degrees of barotrauma in the two ears.

When ear barotrauma does occur, the TM is affected. An otoscopic exam might reveal the following signs (in order of severity):

- Slight redness of the TM.
- Severe redness of the TM and possibly redness of the external ear canal near the TM.
- Clear or bloody fluid in the middle ear (behind the TM).
- A ruptured (i.e. perforated) TM. There will probably be blood in the external ear canal.

There are established grading systems to describe the extent of middle ear barotrauma: Teed (0-4); Modified Teed (0-5); and O'Neill Grading System (0-2).[4] Although a grading system is a useful shorthand within a hyperbaric facility, an ENT physician is unlikely to know any of these grading systems.

It is unusual, but some patients equalize pressure in their ears automatically. They don't have to actively perform a technique to make it happen. Also, a patient with a hole in the TM (from infection, trauma, or a surgical intervention) should equalize pressure in that ear automatically (through the perforation, rather than the Eustachian tube). An ENT physician can place pressure equalization (PE) tubes in the TMs of a patient who cannot effectively perform an equalization technique.

A hyperbaric patient who is referred to an ENT physician for PE tubes should get tubes in both ears (i.e. bilateral) even though one of the ears may appear normal on exam. If only one PE tube is placed, any pressure in the nasopharynx (from attempting an equalizing technique) may escape through the PE tube, instead of equalizing the other ear. PE tubes can become blocked with ear wax, blood, or drainage. Pre-treatment ear exams should be performed to ensure the tubes are not blocked.

Normal TM (right ear)

PE Tube in TM (right ear)

EQUALIZING TECHNIQUES

There are several techniques to equalize middle ear pressure. Two of the most common and effective techniques are the Valsalva and Frenzel maneuvers. Both involve increasing pressure in the nasopharynx to force air through the Eustachean tube into the middle ear. The Valsalva maneuver is a moderately forceful attempted exhalation against a closed airway. It is performed by:[7]

1) Pinching the nostrils
2) Closing the mouth
3) Attempting to expel air (as if blowing up a balloon) without letting the air escape through the nose or mouth

The Frenzel maneuver could be considered a gentler version of the Valsalva. The Frenzel maneuver uses the tongue like a piston against the roof of the mouth. It is performed by:[1]

1) Pinching the nostrils
2) Placing the tongue against the roof of the mouth (instead of closing the mouth)
3) Gently moving the back of the tongue upwards and backwards to compress the air

Other common techniques do not rely on increasing pressure in the nasopharynx, but instead manipulate the muscles that will encourage the Eustachian tubes to open. Techniques that involve only muscle manipulation include: swallowing, yawning (with the jaw open as far as you can), thrusting the jaw forward, and the Toynbee maneuver. The Toynbee maneuver is performed by pinching the nostrils and swallowing.

Regardless of the technique used, leaning the head to one side (so it stretches the neck) may make the ear pointed upward easier to equalize. Imagine trying to lay your right ear on your right shoulder. This should help equalize your left ear. This technique can be used in combination with one of the other techniques above. Before asking patients to do this neck stretch, make sure they do not have a neck injury.

EAR EQUALIZING TIPS

The following may help patients equalize pressure in their ears:

- Sit patients upright, if possible. It is easier to equalize pressure in the ears if you are vertical, rather than lying supine. In a smaller diameter chamber (like many monoplace chambers), this may not be practical. Also, patients may be uncomfortable sitting upright for the entire treatment.
- Have patients stretch their necks while attempting to equalize. Patient in the monoplace chamber are typically lying on their backs. If the chamber operator sits close to the head end of the chamber, having the patient "look at me" or "look away from me" will cause the patient to stretch the neck to one side or the other.
- Use a training aid. There is a biofeedback device available to help patients learn the Valsalva maneuver. It is a balloon inflated through the nose instead of the mouth. In order to inflate the balloon through the nose, you must increase the pressure in your nasopharynx. This device is marketed for the treatment of "glue ear" in children.

- Give the patient a drink. Many people find it difficult to swallow or perform a Toynbee maneuver with a dry mouth. There are concerns about spilling the drink and about trapped gas spaces in the drink container. An option is to use a needleless 60cc syringe filled with the beverage. The

patient can drink from the syringe. It should not spill; and if there is no air space in the syringe, it should not be affected by pressure change. Some monoplace facilities will not give food or drink to hyperbaric patients who is unattended and lying on their backs because of concerns about choking.

- Decongestants may make it easier for patients to equalize pressure, but only work within a certain timeframe. If the patient is taking an oral decongestant (e.g. pseudoephedrine, phenylephrine), it takes about 30 minutes to start working after taking the pill(s). Make sure the patient takes the medication at least 30 minutes before the treatment starts. If the patient is using a decongestant nasal spray (e.g. oxymetazoline, phenylephrine), it will start working almost immediately. Oral decongestants and nasal sprays may wear off in 4-6 hours. Some of these medications come in 12 hour and 24 hour varieties; but keep in mind the medication may wear off sooner in some patients. Know which medicine the patient is taking; and make sure it isn't likely to wear off in the middle of the hyperbaric treatment.

Decongestants, like all medication, should be ordered by a provider (e.g. physician, PA, NP); and should only be administered by a person licensed by the State to do so.

TEACHING PATIENTS TO EQUALIZE PRESSURE

It is difficult to teach patients how to equalize pressure in their ears; and it is difficult for patients to learn. There are several barriers to effective patient education:

- Prior to the first treatment (when the patient has not experienced the sensations involved in pressure change), it is difficult for some patients to understand the need for pressure equalization.
- It is not easily relatable. Many patients have had little or no experience actively equalizing ear pressure. Their life experience may not include air travel, and experience with SCUBA diving is much less likely. Some patients have had painful air travel experience, making them more anxious about hyperbaric treatment. Even for patients with pain free air travel experience, the pressure difference in aircraft is less and changes more gradually than in the hyperbaric chamber.
- Most patients do not understand the relevant anatomy, making it more difficult to understand the techniques we try to teach.
- It can be embarrassing for patients to admit they do not understand. Many patients will confirm their understanding, even though they truly do not.
- When you and the patient are not fluent in the same language, it is very difficult for them to understand and you to assess their understanding. Out of politeness, many patients will respond affirmatively (e.g. nod, smile, say "yes"), even when they do not understand.
- Although many techniques might be effective in the chamber, we cannot assess their effectiveness outside the chamber. Techniques that involve only muscle manipulation are not likely to cause a visible change in the TM, because there is no pressure differential across the Eustachian tube. Therefore, there is nothing for us to see with an otoscope. When a patient performs the Valsalva or Frenzel maneuver, we should be able to see the TM bulge outward. This does not guarantee the technique will be effective inside the chamber; but it does verify the patient can perform at least one technique correctly.
- Some patients believe the Valsalva maneuver will cause an injury. It should be a relatively gentle maneuver; but some patients only puff out their cheeks and do not actually increase the pressure in the nasopharynx. Many patients do not blow hard enough when performing the Valsalva maneuver to make it effective.

When performing the Valsalva maneuver, there can be an increase in inner ear fluid (perilymph) pressure, particularly when straining. If the patient is straining hard or turning red in the face without successfully equalizing pressure, this is not an appropriate technique. The concern is that the patient could rupture the round or oval window (i.e. perilymph fistula). The risk occurs if the patient is being pressurized in the chamber and there is enough vacuum in the middle ear (typically when the pain experience is higher than 5) at the same time the patient is straining hard. The combination of vacuum in the middle ear with increased perilymph pressure could lead to a perilymph fistula. Although serious, perilymph fistula is an extremely rare and unlikely occurrence in hyperbaric patients, particularly if we keep the patient's pain experience less than 5. The Valsalva maneuver should not be used during decompression of the chamber, when the volume of gas is trying to expand. Because of the issues mentioned above, some hyperbaric facilities do not teach the Valsalva maneuver to their patients.

New patient education typically happens one or more days prior to the first hyperbaric treatment. The quality of this initial education is improved by a knowledgeable and conscientious instructor. The level of provider involvement in this education varies among hyperbaric

facilities but the best approach is multidisciplinary, so the education can be reinforced by multiple staff members. Chamber operators should be involved in pre-treatment education and continuous reinforcement of proper equalizing techniques. Information from providers, nurses, and technical staff should be consistent (i.e. not conflicting/contradictory). It is a good idea to review/refresh this education on first day of treatment and give the patient a reminder about equalizing ear pressure prior to each treatment.

When translators are used, it is important to remember they are interpreting your intent, rather than just stating your words in another language. Translators should be taught to clear their own ears, so they can better help instruct patients. Having family members, especially adult children of older patients can be very helpful. Adult children are usually better able to assess their parents understanding than you are.

It is a good idea to teach patients more than one equalizing technique before attempting the first hyperbaric treatment. Even if the patient has properly demonstrated a technique outside the chamber, the true test of its effectiveness is the first pressurization inside the chamber. It will be more difficult for patients to learn a new technique while inside the chamber, particularly if they are having discomfort in the ears.

PREVENTING BAROTRAUMA DURING COMPRESSION

Whenever the chamber is being compressed or decompressed, the chamber operator must be vigilant about the patient's tolerance of pressure change. During compression, patients will likely need to equalize several times within the first 5 psig (10 fsw). This is the pressure range where you can identify the patient who does not have an effective equalizing technique; and where ear barotrauma is more likely to occur. Although patients must be monitored throughout the entire pressurization, the chamber operator should be more alert to possible barotrauma in the following patients:

- New patients. These patients have not had a chance to practice equalizing techniques.
- Patients who demonstrated difficulty equalizing during previous treatments.
- Patients with a language barrier.
- Patients who may have cognitive or learning disabilities (e.g. dementia)
- Patients who have an acute change in health affecting the nasopharynx (i.e. cold, allergies)

Some patients will immediately let you know they are experiencing difficulty and others will not. Do not wait for the patient to report a problem. Watch for signs and symptoms of ear barotrauma. These signs and symptoms vary widely but may include:

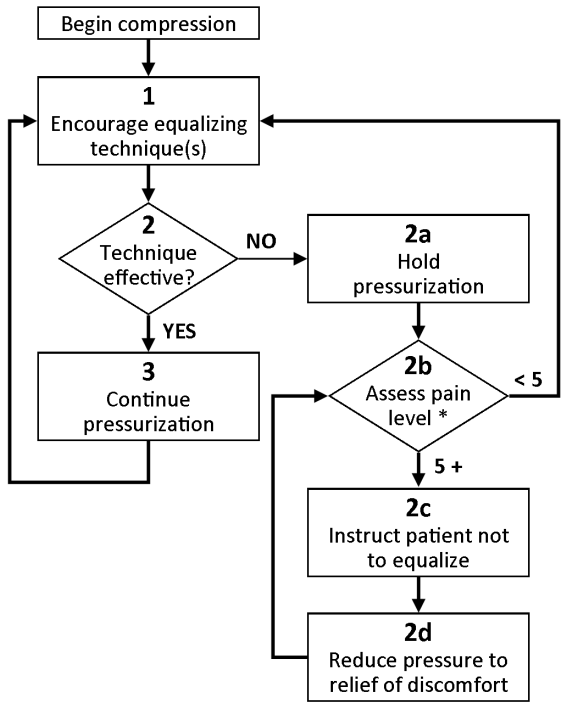
- Difficulty hearing or responding to the chamber operator's communications.
- Tugging on the earlobe or placing a finger in the external ear canal.
- Constant repeated attempts to equalize pressure in the ears (i.e. Valsalva, yawn, jaw thrust) with no delay between attempts.
- Pained/confused/concerned expression on the face.

If you are not sure what is happening to the patient, interrupt the pressurization and hold the chamber pressure where it is. This allows you time to figure out if there is a problem; and may prevent a more severe injury. Simply stated – we must get to know our patients, recognize when they are in distress, and act accordingly.

When pressurizing the chamber, the objective is for patients to equalize pressure before exceeding a pain level of 5 (i.e. discomfort or pain). Once the patient experience exceeds level 5, it is more difficult to equalize pressure because the vacuum holding the Eustachian tube shut may be too strong for the patient to overcome. Continuing to increase chamber pressure will increase the amount of vacuum and barotrauma. If the patient experience exceeds 5, the chamber operator should immediately pause the pressure change (i.e. hold the chamber at the current pressure) and reduce the chamber pressure to the point of relief. The objective is not to reduce the pressure to zero or to get the pain experience to zero, but the pressure reduction should be at least 1.0 psig (2 fsw). The objective of this pressure reduction is to lessen the vacuum on the Eustachian tube. This should minimize injury and hopefully allow the patient to equalize pressure more easily.

Once the chamber pressurization is paused, the patient should be encouraged to perform one of the equalization techniques. The algorithm below is a patient compression strategy (following the procedure described above) that should minimize the risk of barotrauma. This algorithm uses patient feedback to determine the effectiveness of equalization techniques. A similar algorithm, using in-chamber tympanometry (rather than patient feedback) to assess effectiveness of equalization techniques, demonstrated 0/50 subjects experienced middle ear barotrauma compared to 16/50 subjects in the control group.[2] Based on the results of this experiment, the

algorithm proposed here should be effective, if we communicate clearly with the patient and get reliable feedback. Hyperbaric facilities should consider developing a protocol empowering the chamber operator to manage this process. The chamber operator should also know when to involve the provider (e.g. physician, PA, or NP).



** The pain level is based on the modified pain scale above.*

If this is a patient's first treatment, it is prudent to use a slow compression rate initially. After patients have successfully completed several cycles of equalizing pressure in the ears (i.e. steps 1, 2, and 3), they may be able to tolerate a slightly faster compression rate. If you are able to stay on the left side of the algorithm during the entire compression, it is extremely unlikely the patient will have an ear barotrauma. If you have to move to the right side of the algorithm (i.e. steps 2a-2d), these steps should be executed in rapid succession. If you wind up on the right side of the algorithm more than two or three times in the first 5 psig (10 fsw) of pressure change, it is an indication the patient probably does not have an effective equalizing technique. The likelihood of an ear barotrauma is higher. This treatment attempt should probably be terminated so the patient can be re-educated and re-assessed.

Typically, it is the responsibility of a provider to make the decision to terminate a treatment. However, facilities should consider developing a protocol for the chamber operator to terminate a treatment in situations like the one described above. If the patient can equalize pressure effectively for the first 5 psig (10 fsw), but then starts having difficulty at some greater pressure, it is an indication the patient had a working technique up to a point. The likelihood is this patient could continue to equalize effectively with some coaching. The more times you have to move to the right side of the algorithm (i.e. execute steps 2a-2d), the higher the likelihood of an ear barotrauma. At some point, there is a judgment call to be made about whether to terminate the treatment.

As the patient progresses through more treatments the chamber operator should have a good idea of how the patient will tolerate pressurization. Whenever a patient reports an issue or the pressurization is interrupted, the chamber operators should document the event and their actions. If you must execute any of steps 2a-2d, even once, the patient may have some degree of barotrauma and should be assessed by a licensed person (e.g. RN, NP, PA, physician) when removed from the chamber.

UNREPORTED EAR BAROTRAUMA

Some patients have ear barotrauma and do not report it. Possible reasons include:

- We failed to properly educate the patient.
- The patient assumed a little discomfort was normal. Some patients do not understand that they should report any discomfort or pain during pressure change.
- The patient decided to "tough it out" because it wasn't that bad. A stoic male might believe it is a sign of weakness to report discomfort or pain.
- The patient did not want to inconvenience anyone else. Patients in a multiplace chamber might be reluctant to interrupt the pressurization of the rest of the group.
- The patient has diminished sensation and is unaware of the problem.

Unreported ear barotrauma is a reason to consider performing an ear exam after every hyperbaric treatment. For the patient with an unreported barotrauma, the provider (i.e. physician, PA, NP) needs a chance to re-assess this patient and determine if medication or a change to the treatment plan is indicated. The patient who experiences an ear barotrauma may have difficulty equalizing the following day.

BAROTRAUMA DURING DECOMPRESSION

Ear barotrauma during decompression (i.e. "reverse ear block", "reverse ear squeeze") is a very rare occurrence because the middle ear can normally vent out excess gas through the Eustachian tube. One possible scenario for ear barotrauma during decompression exists with the patient

taking decongestant medication. If the decongestant wears off during the hyperbaric treatment, there may be enough swelling around one or both Eustachian tubes to prevent gas from venting out.

OVERNIGHT/DELAYED EAR BAROTRAUMA

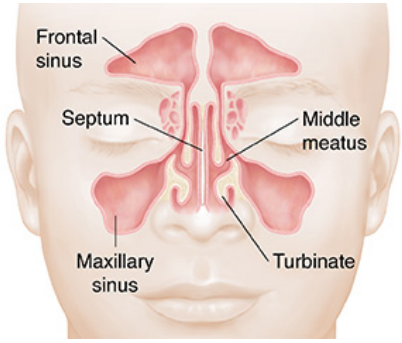
The tissues in the middle ear slowly absorb oxygen, creating a slight negative pressure in the middle ear. This absorption of oxygen is normal, and happens to all of us. Chewing, yawning, or swallowing is enough to open the Eustachian tube and equalize middle ear pressure in most people. People with Eustachian tube dysfunction may have a chronically retracted TM because they do not automatically equalize with chewing, yawning, or swallowing.

In monoplace chambers compressed with oxygen, the act of equalizing pressure in the middle ear causes additional oxygen from the chamber to enter the middle ear. Therefore, a monoplace hyperbaric patient has more oxygen than normal in the middle ear after each hyperbaric treatment. This additional oxygen is slowly absorbed by the tissues in the middle ear with a potential for greater vacuum than normal.[3] Most patients continue to equalize middle ear pressure normally throughout the evening; but some do not. Because of this phenomenon, it is possible to have a patient tolerate chamber pressurization with no difficulty, have a normal ear exam post-treatment, and come in the following day with evidence of a mild ear barotrauma on pre-treatment exam. The barotrauma occurred throughout the evening from absorption of the additional oxygen in the middle ear.

Monoplace facilities should consider performing ear exams before every hyperbaric treatment, to identify the patients who experience this problem. Providers may wish to prescribe decongestants for these patients. Hyperbaric facilities that utilize oxygen-filled chambers should consider encouraging patients to equalize throughout the evening after each treatment. Overnight barotrauma is generally not seen in chambers compressed with air.

BAROTRAUMA TO SINUSES AND TEETH

Sinus passages are narrow conduits that connect the sinuses to the nasal cavity. They are susceptible to congestion. The Eustachian tube can be opened by muscle manipulation, but muscle manipulation cannot open the sinus passages. A patient with a cold or allergies is likely to have swelling around the sinus passages and may be more likely to have a sinus barotrauma (i.e. “sinus block”, “sinus squeeze”). For patients with nasal congestion, we must rely on medication to manage sinus barotrauma risk. Sinus barotrauma in hyperbaric patients is rare; but could occur during compression or decompression. When a hyperbaric patient is taking decongestants for nasal congestion, it is important that the medication not wear off in the middle of a hyperbaric treatment.



Symptoms of sinus barotrauma occur during pressure change and progress rapidly. Typical signs and symptoms of sinus barotrauma include:

- Dull pain in the forehead (frontal sinuses), below the eyes (maxillary sinuses), or upper teeth (referred pain from the maxillary sinuses).
- Severe, sharp pain in the forehead (frontal sinuses), below the eyes (maxillary sinuses), or upper teeth (referred pain from the maxillary sinuses).
- Bloody nose.

On the first sign of sinus barotrauma, the chamber operator should immediately stop pressure change and reverse the direction of pressure to the point of relief. Residual soreness can make the point of relief difficult to determine. At this point, the provider should be notified to take over the care of this patient. A Valsalva, Frenzel, or Toynbee maneuver might be helpful. If a decongestant nasal spray is available inside the chamber, it may also help the patient equalize sinus pressure.

If the patient is having sinus pain during compression the provider should consider terminating the treatment to avoid sinus barotrauma during decompression (at the end of the treatment). Patients who experience a sinus barotrauma will likely have residual soreness after the event.

Tooth barotrauma (i.e. “barodontalgia”, “tooth squeeze”) could occur if there is a gas space inside/under a tooth or under dental work (e.g. filing, crown). The typical symptom is soreness or pain in one tooth. If there is soreness or pain in several upper teeth, it is most likely maxillary sinus barotrauma. Tooth barotrauma in hyperbaric patients is rare; but symptoms could occur during or after compression or decompression. If tooth barotrauma

occurs during compression, the compression should be stopped and the patient removed from the chamber. Regardless of when the symptoms occur, a patient with a tooth barotrauma should be referred to a dentist for treatment.

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