What Chamber Operators Should Know About Ear Barotrauma (and How to Prevent It)

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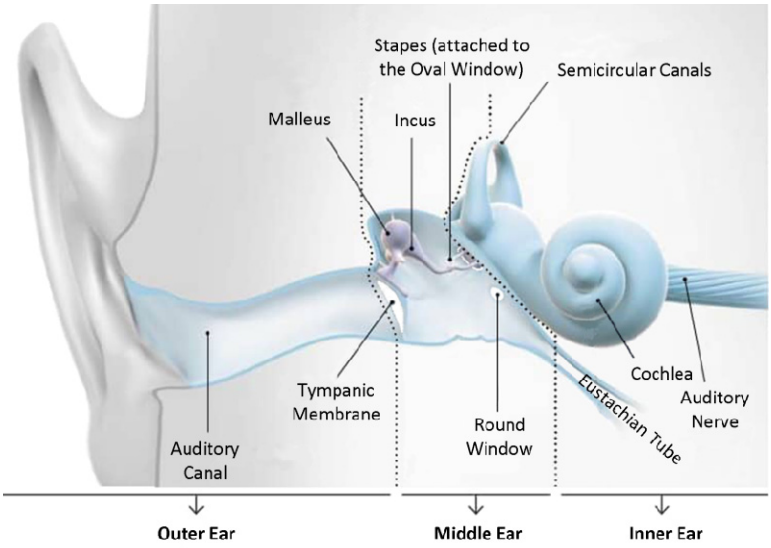
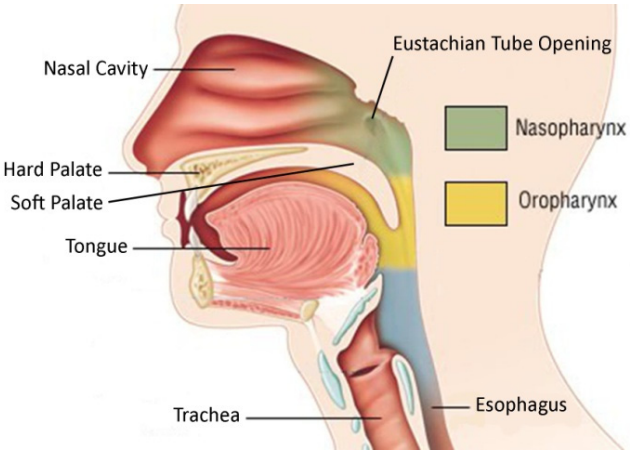
INTRODUCTION

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 conclusion of this article, the reader 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 nasopharynx is the area behind the nose and above the palate. The 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; mild 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 the concept of a pain scale and assign a score to the sensations:

0=NORMAL 1=DULL SOUND 2=FULLNESS 3=DISCOMFORT 4=MILD PAIN 5=SEVERE PAIN

Before the chamber is pressurized, the patient experience should be at zero. As chamber pressure begins to increase, the patient 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 continue to equalize (i.e. the cycle starts over). 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 2 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 5 if the chamber is compressed more rapidly. Slower compression rates give the patient more time to equalize pressure.

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 out at 1 or 2 (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.

It is unusual, but some patients' Eustachian tubes allow them to 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 should equalize pressure in that ear automatically. The hole could be from:

- Infection.
- Trauma. This is unusual; and hopefully we didn't cause it.
- A surgical intervention to place a slit or hole in the TM (i.e. myringotomy).
- A surgical intervention to place a pressure equalization (PE) tube in the TM.

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 a pressure equalizing technique) may escape through the PE tube, instead of allowing pressure to equalizing in the other ear.

Normal TM (right ear)

PE Tube in TM (right ear)

EQUALIZING TECHNIQUES

There are several techniques to equalize middle ear pressure. One of the most common and effective techniques is called the Valsalva maneuver. It involves closing the mouth, pinching the nostrils shut, and then increasing the pressure in the nasopharynx by blowing without letting any air out through the mouth or nose. 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 involves pinching the nose and swallowing. The Frenzel maneuver is a combination of muscle manipulation and some air movement. It involves pinching the nose and pushing the back of the tongue into the roof of the mouth so it works like a piston on the soft palate, pushing air into the nasopharynx.

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 a patient to do this neck stretch, make sure he does not have a neck injury.

EAR EQUALIZING TIPS

The following may help patients equalize pressure in their ears:

- Sit the patient 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, the patient may be uncomfortable sitting upright for the entire treatment.

- Have the patient stretch his neck while attempting to equalize. The patient in the monoplace chamber is typically lying on his back. 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 his 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 you inflate through your nose instead of your 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 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 there will be no air space in it. Some monoplace facilities will not give food or drink to a hyperbaric patient who is unattended and lying on his back because of concerns about choking.
- Decongestants may make it easier for a patient 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:

- It is not easily relatable. Most patients are not SCUBA divers; and have had little or no experience actively equalizing ear pressure. Any experience they have (e.g. traveling in an airplane) involves pressure differences that are smaller and change more gradually than the chamber.
- Most patients do not understand ear anatomy, making it more difficult to understand the techniques we try to teach them.
- 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 maneuver, we should be able to see the TM bulge outward. Unfortunately, this does not guarantee the technique will be effective when there is a pressure differential across the Eustachian tube (i.e. inside the chamber).
- Some patients believe that increasing the pressure in the nasopharynx (i.e. 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 cerebrospinal fluid (CSF) 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 his 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 3 or higher) at the same time the patient is straining hard. The combination of vacuum in the middle ear with increased CSF pressure in the inner ear 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 3. The Valsalva maneuver should not be used during decompression of the chamber. When the volume of gas in the middle ear is expanding, we should not try to add more. Because of the issues mentioned above, some hyperbaric facilities do not teach the Valsalva maneuver to their patients.

It is a good idea to teach the patient 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 the patient to learn a new technique while inside the chamber, particularly if he is having discomfort in the ears.

PREVENTING BAROTRAUMA DURING COMPRESSION

Whenever the chamber is being compressed or decompressed, the chamber operator must be vigilant of the patient's tolerance of pressure change. During compression, the patient 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 all patients must be monitored throughout the 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 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 among patients and may include:

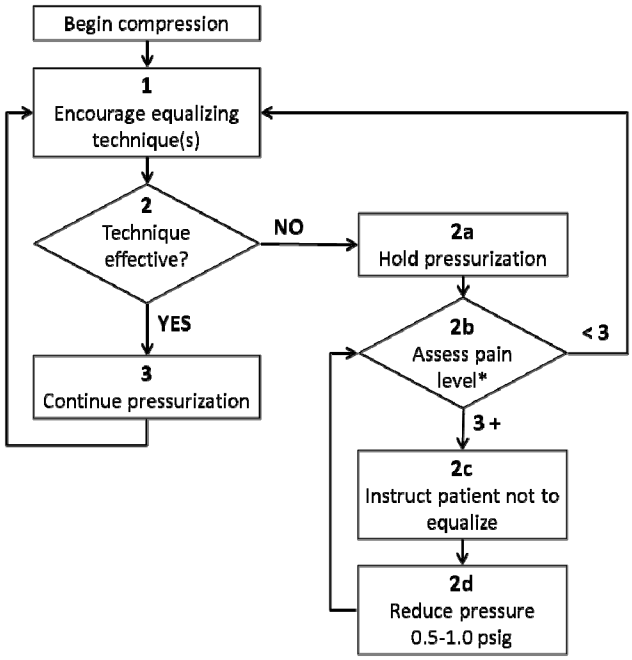
- Difficulty hearing or responding to the chamber operator's communications.
- Tugging on the earlobe or placing a finger in the external ear canal.

- Constant repeated attempts to equalize pressure in the ears (i.e. Valsalva, yawn, jaw thrust) with no delay between attempts.
- Pained expression on the patient's 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.

It is a good idea for the chamber operator to be involved in pre-treatment education and continuous reinforcement of proper ear equalizing techniques. 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 the patient to equalize pressure before reaching a pain level of 3 (i.e. discomfort). Once the patient experience reaches level 3 or higher (i.e. discomfort or pain), it is more difficult for the patient 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 has reached 3 or higher, the chamber operator should immediately pause the pressure change (i.e. hold the chamber at the current pressure) and reduce the chamber pressure approximately 0.5-1.0 psig. The objective of this pressure reduction is to lessen the vacuum on the Eustachian tube, minimizing the injury and hopefully allowing the patient to equalize pressure more easily. In some cases, the pressure might need to be reduced another 0.5-1.0 psig for the patient to have relief. Once the chamber pressurization is paused, the patient should be encouraged to perform one of the equalization techniques. The flowchart below is a patient compression strategy (following the procedure described above) that should minimize the risk of barotrauma. 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 0-5 scale discussed in this article.

If this is a patient's first treatment, it is prudent to use a slow compression rate initially. After the patient has completed several cycles of successfully equalizing pressure in the ears (i.e. steps 1, 2, and 3), he may be able to tolerate a slightly faster compression rate. If you are able to stay on the left side of the chart 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 chart (i.e. steps 2a-2d), these steps should be executed in rapid succession. If you wind up on the right side of the chart more than two or three times in the first few psig of pressure change (approximately 5 psig/10 fsw), 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 few psig, but then starts having difficulty at some pressure greater than approximately 5 psig/10 fsw, 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 chart (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 operator should document the event and his 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 a little discomfort or pain.
- The patient did not want to inconvenience anyone else. In a multiplace chamber, one patient 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 for hyperbaric facilities 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

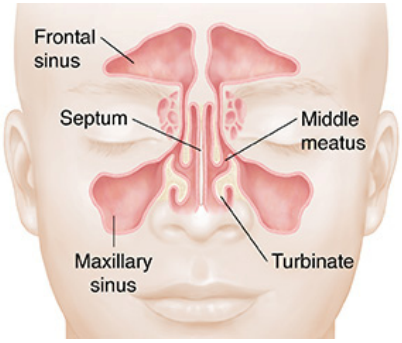
ear can normally vent out excess gas through the Eustachian tube. One possible scenario for ear barotrauma during decompression exists with the patient taking decongestant medication. If the decongestant wears off during the hyperbaric treatment, there may be enough swelling around one or both Eustachian tubes to prevent gas from venting out.

OVERNIGHT 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 not be able to equalize middle ear pressure as easily as others. These people may have a chronically retracted TM because of the constant vacuum in the middle ear and tend to have more difficulty equalizing middle ear pressure in the hyperbaric chamber.

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 the hyperbaric treatment. This additional oxygen is slowly absorbed by the tissues in the middle ear and a greater vacuum than normal is created. 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 the absorption of the additional oxygen in the middle ear. Most patients do not have this experience, but some do. This is a reason why monoplace facilities should consider performing ear exams before every hyperbaric 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 offers us a mechanism to equalize pressure in the middle ear; but there is no such mechanism for sinuses. 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.

The patient with a sinus barotrauma will likely have residual soreness after the event.

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. Pressure reduction of 0.5-1.0 psig may be adequate; but residual soreness can make this difficult to judge. At this point, the provider should be notified to take over the care of this patient. If a decongestant nasal spray is available inside the chamber, it may help the patient equalize sinus pressure. A Valsalva, Frenzel, or Toynbee maneuver might also be helpful. If the patient is having sinus pain during compression, and decongestant spray is not available, the provider should consider terminating the treatment to avoid sinus barotrauma during decompression (at the end of the treatment).

Tooth barotrauma (i.e. “barodontalgia”, “tooth squeeze”) could occur if there is a gas space inside 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 a 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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CONTINUING EDUCATION CREDIT

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