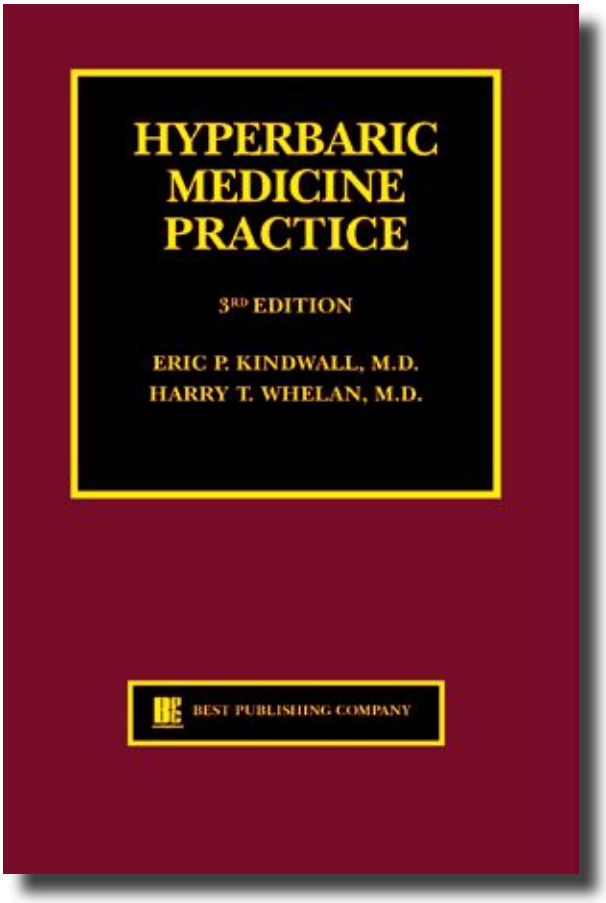
Quick Reference Guide on the Units of Measure in Hyperbaric Medicine

This quick reference guide is excerpted from Dr. Eric Kindwall's chapter "The Physics of Diving and Hyperbaric Pressures" in *Hyperbaric Medicine Practice*, 3rd edition.



www.BestPub.com

INTRODUCTION

The physics of diving and hyperbaric pressure are very straightforward and are defined by well-known and accepted laws. Gas under pressure can store enormous energy, the amounts of which are often surprising. Also, small changes in the percentages of the various gases used are greatly magnified by changes in ambient pressure. The resultant physiologic effects differ widely depending on the pressure. Thus, diving or operating a hyperbaric facility requires gaining complete knowledge of the laws involved to ensure safety.

UNITS OF MEASURE

This is often a confusing area to anyone new to hyperbaric medicine as both American and International Standard of Units (SI) are used. In addition to meters, centimeters, kilos, pounds, and feet, some pressures are given in atmospheres absolute and millimeters of mercury. Table 1 gives the exact conversion factors between SI and American units.

TABLE 1. PRESSURE CONVERSION TABLE

Multiply given unit by the factor in the appropriate column below

GIVEN UNIT	BAR	ATMOSPHERES	PSIG	Kg/cm^2
1 Bar	1	0.98692	14.504	1.01944
1 Standard Physical Atmosphere	1.0133	1	14.696	1.03322
1 PSIG (gauge pressure)	0.06895	0.68046	1	0.07031
1 Kg/cm^2	1.01944	0.98692	14.504	1
1 Kilopascal	0.01	0.009869	0.14504	0.010194
1 Torracelli (torr)	0.001332	0.001316	0.01934	0.0013046

1 Cubic foot = 28.316 liters

33 feet of sea water = 10.0584 meters

Pressure equivalent of 33 feet of seawater = 1.0256 Kg/cm2 = 14.685 psig

The table above gives exact equivalents, but for the diver or clinical hyperbaric specialist, such precision is not required and the figures given below are more than adequate for practical use.

The American System

I use the term "American System" because even though the units of measurement were originally English, the United Kingdom has now officially gone over to the metric system. The United States is the only country which still uses the original English units.

The pressure of one atmosphere is equal to 14.7 pounds per square inch. This is considered to be the ambient pressure at sea level. By convention, when the term "atmospheres" is used, it always refers to atmospheres absolute. This means that if one is referring to elevated atmospheric pressure in atmospheres, one always includes the ambient air pressure on the surface at sea level, plus the added pressure. Therefore, if one descends 33 feet in sea water, one is at an absolute pressure of two atmospheres. Thirty-three feet is equal to 14.7 pounds per square inch as read on the gauge. This is abbreviated psig. Descending another 33 feet to 66 feet produces an absolute pressure of 3 *atmospheres absolute*, abbreviated ATA. When physicians prescribe treatment pressures, they customarily refer to those pressures in atmospheres absolute. This is an extremely important point to understand since taking a patient to a pressure of 99 feet or four atmospheres absolute would quickly produce oxygen toxicity in a patient if the order were understood to mean three atmospheres as measured on the gauge. *Gauge* pressures do not show the ambient pressure from which one begins pressurization.

The American system is cumbersome. Pressure changes cannot be treated decimally and one must multiply by a conversion factor every time one wants to achieve an equivalency between pounds and feet, or between pounds and atmospheres. The conversion factor for converting feet of sea water (fsw) to pounds per square inch gauge (psig) is 0.445. Thirty-three feet multiplied by 0.445 equals 14.7 pounds per square inch, when rounded to nearest tenth of a pound. Thus, a depth of 100 feet of sea water would equal 44.5 pounds per square inch gauge (psig). *Pounds* and *feet* always denote *gauge pressure* unless they are specifically labeled absolute. The conversion factor of 0.445 should be memorized by anyone using the American system.

The Metric System

The metric system vastly simplifies pressure and depth calculations for diving and hyperbaric work. As a practical matter, 14.7 psig is taken to be the equivalent of 1 kilogram per square centimeter.

In Europe the term "bar" is often used, being equivalent to one atmosphere. However, *bar* is always a *gauge pressure* as opposed to atmospheres which are always absolute. For practical purposes, the pressure at sea level is considered to be one kilogram per square centimeter absolute. Thus, one atmosphere is equal to one kilogram per square centimeter. Going to a depth of 10 meters in sea water, "very close to 33 feet," produces a pressure of two atmospheres. Thus for every 10 meters one descends in the sea, one adds an additional

atmosphere of pressure. In the metric system, *atmospheres* are always given as *absolute*, just as in the American system, and *meters* and *kilograms per square centimeter* are always expressed as *gauge pressures*.

As an aside, it should be pointed out that it is only fortuitous that 10 meters equals one atmosphere and that one kilogram per square centimeter equals atmospheric pressure. The framers of the metric system originally defined the meter as being one ten-millionth of the distance between the North Pole and the Equator.

In the American system it is useful to memorize the number of feet to a given number of atmospheres and to count by 33s (i.e., 33 feet, 66 feet, 99 feet, 132 feet, and 165 feet, corresponding to 2, 3, 4, 5, and 6 atmospheres respectively). In the course of clinical hospital practice, one rarely if ever exceeds a pressure of 165 feet, and going to that pressure would only be in the treatment of decompression illness. In the metric system, ten-meter increments are usually calculated as additional atmospheres are applied. Thus, it is easy to equate 50 meters with 6 atmospheres absolute (ATA), whereas in the American system one has to memorize that the pressure at six atmospheres is 73.4 pounds per square inch gauge (psig) or 165 feet.

Kilopascals

There is a growing trend to express pressures in terms of SI units or kilopascals. One hundred kilopascals equals 1 atmosphere or 1 kilogram per square centimeter. Rigid convention specifies that kilopascals are always an expression of absolute pressure. Thus, 250 kilopascals equals 2.5 atmospheres, or 1.5 kilograms per square centimeter gauge. The reader should be cautioned, however, that not all authors use kilopascals as absolute pressures and occasionally one may find them expressed as gauge pressures. Thus, be careful to double check the author's frame of reference when reading manuscripts in which pressures are expressed as kilopascals.

Millimeters of Mercury

An older unit of measure typically used to express pressures of one atmosphere or less is the millimeter of mercury sometimes called the Torr. Normal atmospheric pressure at sea level is accepted as being equal to 760 millimeters of mercury. This is abbreviated mmHg. Partial pressures of gases dissolved within the body are often expressed in mmHg. For practical purposes, the ambient pressure of oxygen in air at normal sea level pressure is 160 mmHg. The partial pressure of nitrogen is taken to be 600 mmHg. The trace gases, helium, neon, argon, krypton, and xenon are usually ignored, even though argon represents nearly one percent of the inert gas moiety.