Script for the educational module, entitled "The Acid-Base CLinIMApp: A new way of teaching Arterial Blood Gas interpretation"

Slide 1

This educational module, entitled "The Acid-Base CLinIMApp: A new way of teaching Arterial Blood Gas interpretation", has been composed by Bob Demers. References pertaining to this module are incorporated within the verbatim script of the audio track of this video. That script is downloadable from the same site from which this video was accessed.

Slide 2

This module is a so-called "Interactive Video™". You will need to view it on a system which provides both audio and video. At various points during the presentation, a chime will sound. At that point, viewers are required to highlight the words or phrases in their handout which correspond to the words/phrases which display in yellow text in the video images. Before we proceed with the video, viewers should ensure that they have a hard copy of the handout, and a highlighter, in hand. If either of these is not available, pause the video at this time in order to secure them.

Slide 3

At the conclusion of this module, each viewer will be expected to demonstrate her/his ability to teach the intricacies of Arterial Blood Gas (or "ABG") interpretation employing diagrammatic tools, such as the "Acid-Base CLinIMApp™". Viewers' acquisition of these skills will be confirmed by the satisfactory completion of a Post-Test, the components of which will be drawn from a test pool comprised of twenty items. If anyone to whom this module has been assigned has already mastered its' content, s/he will be allowed to "challenge out" of it by satisfactorily completing a Pre-Test comprised of items drawn from the same question pool.

Slide 4

If they haven't already done so prior to watching this video, viewers of this educational module are advised to view the module entitled "The Hendersonian approach: A new way of learning Arterial Blood Gas interpretation". In that presentation, I suggest that the Henderson Equation[1] constitutes a far simpler and more straightforward mathematical representation of acid-base balance than the Henderson-Hasselbalch Equation[2] which succeeded it. Another notable benefit of the Henderson Equation which recommends it to our consideration relates to the ease by which it lends itself to describing acid-base interactions <u>diagrammatically</u>. In this presentation, this attribute will be explored in considerable detail, in an effort to provide the educator/preceptor with tools that s/he might employ to teach arterial blood gas interpretation to students, neophytes, and junior colleagues.

Slide 5

At this juncture, it is useful to review the ranges of normal for the various parameters which relate to ABG analysis. The normal range for arterial carbon dioxide tension, which is symbolized "p_aCO_2", is 35 to 45 torr, inclusive. The normal range for bicarbonate ion concentration, or "$[HCO_3^-]$, is 22 to 26 milliequivalents per Liter, inclusive. The normal physiologic range for hydrogen ion concentration, or "[H^+]", is 35 to 45 nanomoles per Liter, inclusive. And the homeostatic range for arterial pH, "pH_a", is 7.35 to 7.45, inclusive. These ranges should be committed to memory.

Slide 6

In the past, **c**ertain researchers have employed pictorial descriptions of acid-base chemistry with some success. In 1931, Hastings and Steinhaus[3] developed an ingenious and intriguing method, the "Tri-Axial system", for displaying ABG data on a triple-axis rectilinear system embedded within a two-dimensional plane. Hekking and his colleagues refined the work of Hastings and Steinhaus in rather elegant fashion in a paper[4] that was published in 1998. On the following slide, we will "build" a Tri-Axial system such as that used by Hastings and Steinhaus and by Hekking and co-workers.

Slide 7

A tri-axial coordinate system is constructed by erecting one axis at a one-hundred-twenty-degree angle from the horizontal. This axis, colored blue, represents the arterial carbon dioxide tension, or "p_aCO_2". Next, a (red) bicarbonate axis is erected at a one-hundred-twenty-degree angle from the previously scribed axis. Finally, a (black) hydrogen ion axis is erected one hundred twenty degrees from the last, which renders it zero degrees from (or congruent with) the horizontal plane. Straight lines (so-called "isopleths"), which are perpendicular to each axis and placed along a logarithmic, and not a linear, scale have been added.

Slide 8

In this Figure, I have arbitrarily chosen to scribe a (blue) line at the p_aCO_2 isopleth representing 62 torr. By definition, this isopleth is the locus of all points for which the prevailing p_aCO_2 is 62 torr. A bicarbonate level of 27 mEq/L was also chosen for illustrative purposes, and appears as a (red) isopleth coinciding with that specific bicarbonate value. Note that 55 nM/L, the hydrogen ion concentration associated with this particular p_aCO_2/[HCO_3^-] pair, can be determined graphically by simply dropping a (black vertical) line from the point of intersection of the p_aCO_2/bicarbonate isopleths down to the (horizontal) [H^+] axis.

Slide 9

In point of fact, a Tri-Axial diagram such as this can be used to identify the unique hydrogen ion concentration associated with any and all combinations of p_aCO_2/bicarbonate in like manner. This attribute of a Tri-Axial coordinate system is its' "signature trait", and is the characteristic behavior which renders it so useful in the geometric description of acid-base balance.

Slide 10

Some students complained that the radially-configured Tri-Axial system depicted in Slide 8 rendered it difficult for them to locate p_aCO_2/[HCO_3^-] data sets, owing to the fact that: 1) specific p_aCO_2, [HCO_3^-], and [H^+] coordinates were often crowded in the vicinity of the origin (the central area of the diagram where the axes converged); and 2) the numerical labels for the respective parameters were difficult to read in the vicinity of the origin. These criticisms were certainly valid, and I sought to rectify these problems by translating the axes in order to achieve spatial separation.

Slide 11

The resulting graphic describes an equilateral triangle, which will be shown in the following slide. Transposition of the axes did not result in a forfeiture of the signature trait of the Tri-Axial strategy, and the graphic still functions as it should. Another feature was requested by several nurses who practiced in the Neonatal Intensive Care Unit (NICU)-- a "pH" axis. This axis is also embedded in the image depicted on the following slide.

Slide 12

Notice that the $p_aCO_2/[HCO_3^-]$ data set which was depicted in Figure 1 (62 torr/27 mEq/L) has been chosen for this figure as well. The signature trait of the Tri-Axial approach is, of course, preserved, insofar as the user is still able to determine the $[H^+]$ value which is uniquely associated with the $p_aCO_2/[HCO_3^-]$ data set chosen earlier. The "pH" axis, added just beneath the $[H^+]$ axis, facilitates the graphical determination of that datum. The $[H^+]$ value of 55 nM/L is seen to coincide with a pH of about 7.26 units.

Slide 13

I have found the Acid-Base Triangle Diagram to be very useful for teaching the principles of acid-base chemistry to neophytes and seasoned practitioners alike. The manner in which the p_aCO_2 axis inclines to the right demonstrates that progressive increases in that parameter will tend to intensify acidemic states by triggering rightward movement along the horizontal axis, corresponding to successive increases in hydrogen ion concentration. Conversely, stepwise increases in bicarbonate will tend to elicit leftward shifts along the hydrogen ion axis, because the bicarbonate ion axis inclines to the left. This attribute reinforces the chemical role of bicarbonate as a strong base. Hence, the use of this diagram can be extremely effective for eliciting an intuitive grasp of the dynamics of an acid-base equilibrium system.

Slide 14

Nomograms of various types have been developed over the years to assist in the interpretation of various categories of laboratory results. Within the realm of acid-base chemistry, the Siggaard-Andersen , the Singer-Hastings, and the Davenport nomograms were especially popular years ago. The Acid-Base Triangle Diagram seen on Slide 12 is, to be sure, a nomogram, but one which I sought to refine further.

Slide 15

This was done by adding information about subsets of ABG data which classify as a particular acid-base abnormality. The Acid-Base Triangle Diagram was converted into an Acid-Base Triangle Map by applying colors and labels to regions of the grid which correspond to various classifications of acid-base derangements.

Slide 16

The p_aCO_2/[HCO_3^-] data pair corresponding to 62 torr and 27 mEq/L, which was selected for illustrative purposes in the previous two figures, has been depicted in this graphic as well. Note that the (yellow) region within which the isopleths converge is labelled "partially compensated respiratory acidemia", identifying the acid-base dysfunction prevailing here by purely geometric (diagrammatic) means. My own bias is to insist that students be able to correctly interpret an ABG report, at the bedside, in the absence of any hard-copy or electronic adjuncts whatsoever. Nevertheless, a map/nomogram such as this can be useful to promote students' mastery of acid-base dynamics.

Slide 17

As intriguing as the Tri-Axial approach to the characterization of acid-base disorders might be, I would be loath to oblige members of the ICU team to employ hard-copy diagrams and a straightedge to undertake clinical decision-making at the bedside. A "solution" such as this would be inelegant in the extreme! Fortunately, the rapid proliferation of computer hardware and software that has occurred in recent years enables anyone with access to a computer to perform rapid and precise mathematical/graphical analyses in real-time. This functionality has been exploited by coding the Acid-Base Triangle Map to run on a digital computer, which liberates the bedside caregiver from mundane drafting chores. The software will run on any networked computer which provides internet access. Hence, it can be made to operate on a desktop, laptop, tablet, or hand-held computer to which browser capability applies. In addition, it can be employed by means of any smartPhone in which a browser is embedded.

Slide 18

I have created a "<u>C</u>omputer-<u>Lin</u>ked <u>I</u>nteractive <u>M</u>apping <u>App</u>lication" (the Acid-Base CLinIMApp™; Demers Consulting Services, Pasadena, CA) to facilitate this process. The application ("app") is accessible, free of charge, by means of the internet. It is coded to generate the type of digital and graphical results described in this presentation at the stroke of a key. After the app launches, the user keys in the two-digit values for p_aCO_2 and [HCO_3^-] which appear in the patient's ABG report. Then, under computer control, the app: 1) scribes lines over the applicable isopleths; 2) displays digital values for the [H^+] and pH_a ; 3) displays step-by-step solutions for the Henderson and the Henderson-Demers Equations; and 4) lists the acid-base disturbance which prevails.

Slide 19

Implementation of the app also enables members of the ICU team to verify that the pH_a reported in the patient's ABG report is valid (compatible with the Henderson and the Henderson-Hasselbalch Equations) and to confirm that the team members' characterization of the prevailing acid-base dysfunction is correct. As engaging as the software might be, it is definitely <u>NOT</u> designed to replace caregivers' mastery of acid-base balance. Slavish dependence on any electronic adjunct such as this is to be avoided at all costs. Rather, it is intended to serve as an electronic "preceptor's assistant".

Slide 20

There is absolutely no reasonable facsimile for practitioners' ability to interpret an ABG report after acquiring that skill as an integral element of their skills inventory, and without the assistance of any external adjunct. In fact, if a clinician were to depend on any external contrivance or device in order to solve a clinical problem, that image or gadget would constitute a "crutch" which works to the eventual detriment of caregivers and their patients. There is no substitute for the expertise of bedside clinicians who are able, without the assistance of any external audiovisual/electronic/graphic aids whatsoever, to apply the power of the microprocessor that is located between their ears! Another advantage of this approach resides in the fact that this is the only microprocessor which cannot be mislaid, or rendered inoperative, either because its' batteries have died or alternating current is unavailable.

Slide 21

The Acid-Base CLinIMApp operates from a server based in Chicago, Illinois. It can be accessed from anywhere in the world that is connected to the worldwide web. The following slide depicts a screen shot of the image which displays when the app is implemented.

Slide 22

In this iteration, the values "62" and "27" were keyed in, for the p_aCO_2 and $[HCO_3^-]$ values, respectively. Under computer control, the software has proceeded to generate digital values for $[H^+]$ and pH_a, has scribed lines over the corresponding isopleths, and has characterized the prevailing acid-base disorder as a partially compensated respiratory acidemia.

Slide 23

The app incorporates numerous "touch points", which permit users to "drill down" on the content. By touching/clicking on any of the touch points, users can either inspect or download voluminous written resources which thoroughly explore acid-base theory. This could go far towards enhancing the knowledge, and promoting the collaborative dynamic, of the entire caregiver team. Some seasoned caregivers have learned ABG interpretation by means of flow charts, or so-called "mind maps". These are simply structured algorithms which portray the hierarchy of sequential, branching-logic decisions which practitioners can apply in order to ascertain whatever acid-base disorder might be present. A mind-map pertaining to each of the acid-base dysfunctions embodied in the Acid-Base Map is retrievable by means of its' own touch point.

Slide 24

I routinely assign a series of actual ABG reports to a student, and have that student employ the app to determine the acid-base dysfunction which exists. As part of this assignment, the student is required to activate the app's integral touch points to demonstrate <u>why</u> the given ABG interpretation applies to that data set. By repeated implementation of the app with subsequent ABG data sets, the student acquires the skill of ABG interpretation within a fairly brief timeframe. This, of course, renders the app obsolete, which is precisely the goal which I seek. In other words, the app ceases to be a learning tool, and the student can then use it as a teaching tool when s/he subsequently becomes a preceptor.

Slide 25

Viewers are encouraged to navigate to the Universal Resource Locator ("URL") shown here in order to experience the "look-and-feel" of the app for themselves.

Slide 26

Most viewers of this module are aware that the homeostatic ranges for newborns are slightly different than the ranges which apply to infants, children, and adults. Kristine Karlsen, the nurse who created the S.T.A.B.L.E. program, has published a "Blood Gas Interpretation Chart" which lists the ranges of normal values for p_aCO_2, $[HCO_3^-]$, and $[H^+]$, and I have used those reference ranges to create a "First-Day Acid-Base CLinIMApp", targeted to neonates who are less than twenty-four hours post-partum. The graphic embedded in that app is pictured in the following slide.

Slide 27

The functionality which pertains to this app is identical to that described earlier for its' adult counterpart.

Slide 28

I would respectfully submit that, for far too long, acid-base chemistry, in general, and the Henderson-Hasselbalch Equation, in particular, have been viewed by students with fear and loathing. Pictorial representations of material as abstract as a chemical equilibrium system can confer a visceral understanding of concepts which would otherwise remain elusive, nebulous, and arcane. At the same time, the equations upon which the graphics are based can be employed to generate data that are as precise as the user might choose to make them.

Slide 29

The Tri-Axial strategy used by physiologists in years past can be quite powerful in enabling students to acquire a more intuitive grasp of acid-base concepts. The Tri-Axial Acid-Base Diagram, the Acid-Base Triangle Diagram, and the Acid-Base Triangle Map have been described in detail here. Their features have been exploited to depict, in geometric fashion, the subtle interactions among the chemical species comprising the carbonic acid/bicarbonate equilibrium system, which serves as the principal buffer system of the human organism.

Slide 30

By converting the Acid-Base Triangle Map into a computer app, users are freed from the drudgery of manually scribing lines on a hard-copy printout. The app performs these tasks under computer control, generating high-resolution graphics that instructors and preceptors will, hopefully, consider incorporating into their own teaching practice. In the final analysis, however, these tools must be recognized solely as a teaching strategy, and NOT as a substitute for the practitioner's mastery of acid-base concepts.

Slide 31

In summary, the Acid-Base CLinIMApp is intended to be used by students/instructors as a learning/teaching tool. Ultimately, after students have mastered the crucially important clinical skill of ABG interpretation, they can consider themselves well on their way to becoming clinical preceptors themselves. Once they've assumed the role of mentor, they can proceed to consider using the software as a teaching tool as they subsequently welcome protegés into the clinical team.

Slide 32

No narrative.

References:

1. Henderson LJ. The theory of neutrality regulation in the animal organism. **Am J Physiol** 1908; 21: 427-448.

2. Hasselbalch KA. Die Berechnung der Wasserstoffzahl des Blutes aus der freien und gebundenen Kohlensäure desselben, und die Sauerstoffbindung des Blutes als Funktion der Wasserstoffzahl. **Biochem Zeitschr** 1916; 78: 112–144.

3. Hastings AB, Steinhaus AH. A new chart for the interpretation of acid-base changes and its' application to exercise. **Am J Physiol** 1931; 96: 538-540.

4. Hekking M, Ulenkate HJLM, Speelberg B, Van Puyenbroek HMJ, Goldschmidt HMJ, Gelsema ES. A reappraisal of the tri-axial chart for monitoring arterial acid-base values. **Intensive Care Med** 1998; 24: 977-980.