Anesthesiology
67:391–394, 1987

Evaluation and Comparison of the Distributions of Gastric pH *and Hydrogen Ion Concentration*

Jerry A. Colliver, Ph.D., Laxmaiah Manchikanti, M.D.,† Stephen J. Markwell, B.A.‡*

The shapes of the distributions of gastric *p*H and hydrogen ion concentration [H^+] were determined for each of 68 groups of patients scheduled for elective surgery under general anesthesia. The 68 groups comprised a total of 1,326 patients who had served as subjects in 13 of the authors' previously published studies. In general, the results showed that neither *p*H nor H^+ was normally distributed; most of the *p*H distributions (47 of 68 = 69%) and most of the H^+ distributions (53 of 68 = 78%) showed significant departure from the normal distribution. Moreover, the shapes of the distributions varied, depending upon the conditions under which gastric acidity was assessed. Groups receiving no medication for gastric acidity had positively skewed *p*H distributions (nonsymmetrical distribution with tail pointing to right and majority of cases in lower range), and groups receiving medications for the reduction of acidity had negatively skewed *p*H distributions (nonsymmetrical with tail pointing to left and majority of cases in upper range). The medications produced an inverse relationship between mean *p*H and skewness such that the skewness of the groups decreased from positive to negative as mean *p*H increased. For H^+, all groups had positively skewed distributions, but the distributions were more positively skewed for groups receiving medications for gastric acidity. Again, the medication conditions produced an inverse relationship between mean acidity and skewness such that the groups became more positively skewed as the mean H^+ decreased. Thus, a blanket recommendation of either of the two measures of gastric acidity based on the assumption that the measure has an underlying normal distribution is not warranted by the findings of this study. Based on the argument that *p*H measures the chemical potential of the hydrogen ion and, thus, is directly related to chemical reactions and biological activity, gastric *p*H is recommended as the measure of choice for gastric acidity. (Key words: Acid base equilibrium: distributions of *p*H and H^+; gastric *p*H *versus* H^+; *p*H *versus* H^+.)

ANESTHESIOLOGY RESEARCHERS studying the effects of medications such as cimetidine, metoclopramide, and rantidine on the gastric contents of patients prepared to undergo surgery use *p*H or hydrogen ion concentration (H^+) to measure gastric acidity. Questions have been raised, however, about the appropriateness of using *p*H.[1–6] A primary objection is that gastric *p*H is not normally distributed and, hence, cannot be used with parametric statistical tests of significance (*e.g.*, *t* test, analysis of variance, multiple regression) which assume an underlying normal distribution. The objection seems to be based on the presumptions that H^+ is the natural or direct measure of gastric acidity and that any natural measure is necessarily normally distributed. It follows that a nonlinear derivation, like *p*H which is the negative logarithm of H^+, would not be normally distributed.

The first presumption has been questioned, however, and the point made that, in fact, *p*H is a measure of the chemical potential of the hydrogen ion, and, as such, is directly related to chemical reactions and biological effects. Hence, in actual scientific and clinical practice, *p*H, not H^+, should be seen as the primary measure of hydrogen ion concentration.[7,8] But, regardless of whether *p*H or H^+ is the natural measure, the shape of the distribution of a measured variable is *not* dependent on whether the variable is fundamental or derived. A natural measure may or may not be normally distributed, just as a derived measure may or may not be normally distributed. Moreover, the shape of the distribution of a measured variable is not constant across all conditions, but depends upon a number of factors. Hence, the shape of the distribution of a variable measured under given conditions must be determined empirically, whether the variable is fundamental or derived. The purposes of the present study were 1) to determine the shapes of the distributions of pH and H^+ under different conditions, 2) to compare the shape of each of these distributions with that of the normal distribution, and 3) to check the invariance of the shapes of the distributions under different experimental conditions.

Methods and Materials

Data were available from 1,326 patients who had served as subjects in 13 of our previously published studies.[9–17]§¶**†† Twelve of the studies evaluated the

* Research Professor and Director, Division of Statistics and Measurement.

† Director, Department of Anesthesiology.

‡ Researcher, Division of Statistics and Measurement.

Received from the Division of Statistics and Measurement, Southern Illinois University School of Medicine, Springfield, Illinois; and the Department of Anesthesiology, Lourdes Hospital, Paducah, Kentucky. Accepted for publication April 20, 1987.

Address reprint requests to Dr. Colliver: Division of Statistics and Measurement, Southern Illinois University School of Medicine, Springfield, Illinois 62708.

§ Manchikanti L, Marrero TC: Effect of cimetidine and metoclopramide on gastric contents in outpatients. Anesth Rev 10:9–16, 1983

¶ Manchikanti L, Grow JB, Colliver JA, DeMeyer RG, Hohlbein LJ: Introvenous cimetidine and metoclopramide for modification of gastric acidity and volume in outpatient surgery. Anesth Rev 8:8–14, 1986

** Manchikanti L, Hawkins JM, McCracken JH, Colliver JA: Effect of cimetidine, metoclopramide and oral premedication on gastric contents in pediatric outpatients. Anesth Rev 12:37–43, 1985

†† Manchikanti L, Hawkins JM, McCracken JE, Roush JR: Evaluation of preanesthetic glycopyralate and cimetidine for acid aspiration prophylaxis in children. Eur J Anesthesiol 1:123–131, 1984

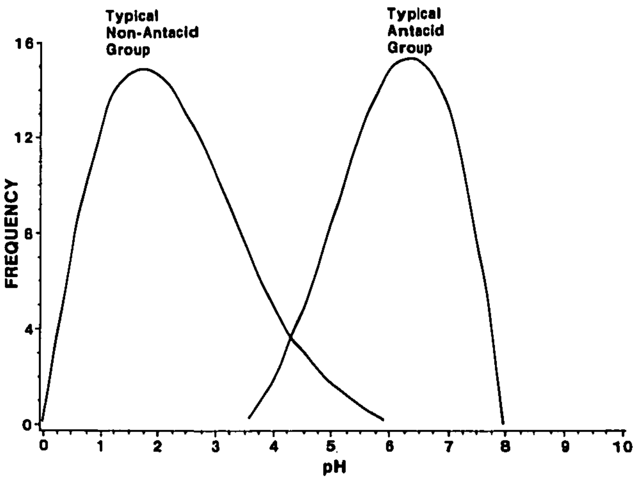

FIG. 1. Schematic representation showing the *p*H distributions of the typical non-antacid and antacid groups. The graphs illustrate the finding that skewness shifted from positive to negative as mean *p*H increased.

effects of medications, such as cimetidine, ranitidine, glycopyrrolate, bicitra, and metoclopramide, on acidity and volume of gastric contents of patients prepared to undergo elective surgery. The remaining study assessed the relationships between age and gastric acidity and volume.[14] Two of the 13 studies studied only pediatric patients,**†† and one studied only obese patients.[17] The 13 studies were comprised of a total of 68 groups, of which 42 were "antacid groups" and 26 were "non-antacid groups." Patients in the 42 antacid groups received medications for the reduction of gastric acidity (cimetidine, ranitidine, bicitra, and glycopyrrolate); patients in the 26 non-antacid groups received no medication thought to affect gastric acidity. For purposes of this study, the *p*H and H^+ distributions of the 42 antacid medication groups were compared with those of the 26 non-antacid groups.

Inpatients and outpatients scheduled for elective surgery under general anesthesia were studied. Details of the gastric sampling and related techniques are presented in the original articles. In brief, a Salem sump tube was passed into the stomach after induction of anesthesia, and all available gastric contents were aspirated by suction into a graduated mucus trap. Gastric acidity was determined in the laboratory by a Corning® *p*H meter with an Ag/AgCl probe combination electrode.

STATISTICAL METHODS

The *p*H and the H^+ distributions were tested for significant departure from a normal distribution with the Shapiro-Wilk statistical test.‡‡ Descriptive indices of skewness and kurtosis were computed for both distributions.‡‡ For the normal distribution, the skewness and kurtosis indices are equal to 0.00. The sign of the skewness index indicates whether the distribution is positively or negatively skewed, and the magnitude indicates the extent of the skewing. A positively skewed distribution has a tail that points to the right, in a positive direction, with the bulk or majority of cases in the lower range (see curve on left in figure 1); a negatively skewed distribution has a tail that points to the left, in a negative direction, with the majority of cases in the upper range (see curve on right in figure 1). For the kurtosis index, a positive sign indicates the distribution is more peaked than normal, a negative sign indicates the distribution is flatter than normal, and the magnitude indicates the extent the peakedness or flatness departs from normal. Results of statistical tests were considered significant if P values were less than 0.05.

Results

DISTRIBUTIONS OF *p*H

All but one of the 26 groups receiving no medication for the reduction of acidity had positively skewed *p*H distributions. Most of these *p*H distributions (21 of 26 = 81%) were significantly different from the normal distribution ($P < 0.05$), and most (23 of 26 = 88%) were more peaked than the normal. The mean *p*H values for the non-antacid groups were somewhat low, ranging from 1.82–4.88 with mean *p*H less than 3.0 for 85% of the groups. A schematic representation of the *p*H distribution for the typical non-antacid group is presented on the left of figure 1.

The 42 antacid groups differed from the non-antacid groups in that all but one had *p*H distributions that were either negatively skewed (32 of 42 = 76%) or less positively skewed than the *p*H distribution for the non-antacid group in the same study (9 of 42 = 21%). In addition, most of the *p*H distributions (26 of 42 = 62%) for the antacid groups were significantly different from the normal distribution ($P < 0.05$), and half (22 of 42 = 52%) were more peaked than the normal. The mean *p*H for each of the antacid groups generally was higher than that of the non-antacid groups, ranging from 2.31–7.27 with mean *p*H greater than 4.5 for 81% of the groups. The *p*H distribution of typical antacid medication group is presented on the right in figure 1.

In brief, the results showed that medication conditions that resulted in larger increases in mean *p*H also produced greater shifts in skewness. This is depicted by the schematic representation in figure 1, which shows

‡‡ SAS User's Guide: Statistics/1982 Edition. Cary, North Carolina: SAS Institute, 1982

that the increase in mean pH from the typical non-antacid group to the typical antacid group was accompanied by a shift from positive to negative skew. A plot of this relationship between mean pH and group skewness (based on means and skewness indices for all 68 groups) is presented in figure 2, which shows that group skewness decreased from positive to negative as mean pH increased ($r = -0.75$; $P = 0.0001$).

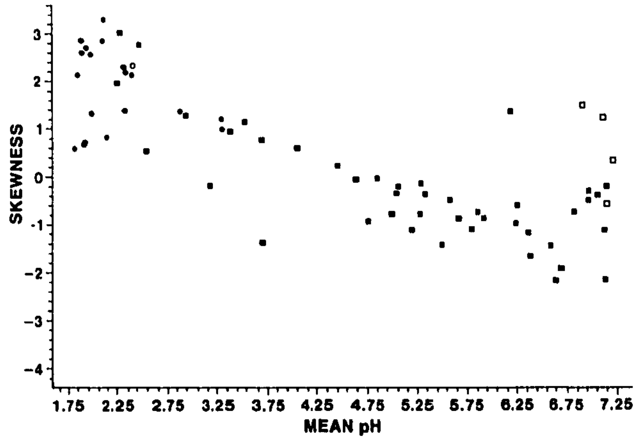

FIG. 2. The skewness of the pH distributions shifted from positive to negative as mean pH increased. In general, the non-antacid groups (circles) had low mean pH and positively skewed distributions, and the antacid groups (squares) had high mean pH and negatively skewed distributions. (The open squares and circles represent groups of obese patients.)

DISTRIBUTIONS OF H^+

All of the groups (68 of 68) in the 13 studies had distributions of H^+ that were positively skewed. Most of these H^+ distributions (53 of 68 = 78%) were significantly different from the normal distribution ($P < 0.05$), and most (59 of 68 = 87%) were more peaked than the normal.

Although all groups had positively skewed H^+ distributions, the distributions were generally more positively skewed for the antacid groups than for the non-antacid groups. The medication conditions that resulted in larger decreases in H^+ also produced greater increases in positive skewness. The plot of this relationship in figure 3 shows that positive skewness increased as mean H^+ decreased ($r = -0.54$; $P = 0.0001$).

Discussion

The results showed that neither the distributions of pH nor the distributions of H^+ were normally distributed, and that the shapes of the distributions depended upon the conditions under which gastric acidity was assessed. These findings might be thought to imply that neither measure of gastric acidity should be subjected to parametric statistical tests which assume an underlying normal distribution. Fortunately, the central limit theorem and computer simulation studies have shown that basic parametric tests are relatively robust to violations of the normality assumption. That is, the results of these tests have been shown to be accurate even if the measured variable is not normally distributed. On the other hand, the findings might suggest that pH and H^+ can be treated as interchangeable, and that substantive research results will be the same regardless of the measure of gastric acidity used. Unfortunately, with nonlinear transformations like the negative logarithmic, anomalies can occur such that results obtained with the original variable may not be consistent with those obtained with the transformed variable. This was the case in our paper relating age to gastric acidity,[14] in which mean pH showed a decrease in acidity from the pediatric group (1.99) to the adult group (2.40) to the geriatric group (3.32), whereas mean H^+ showed an increase in acidity from the pediatric group (0.0130) to the adult group (0.0181), but a decrease to the geriatric group (0.0104).

In conclusion, the choice between pH and H^+ would best seem to be based on substantive grounds, and not statistical considerations, such as the shape of the measure's distribution. Lacking a compelling alternative position relevant to special circumstances, the general argument presented above, that pH measures the chemical potential of the hydrogen ion and, thus, is directly related to chemical reactions and biological activity, would seem to recommend gastric pH as the measure of choice for gastric acidity.

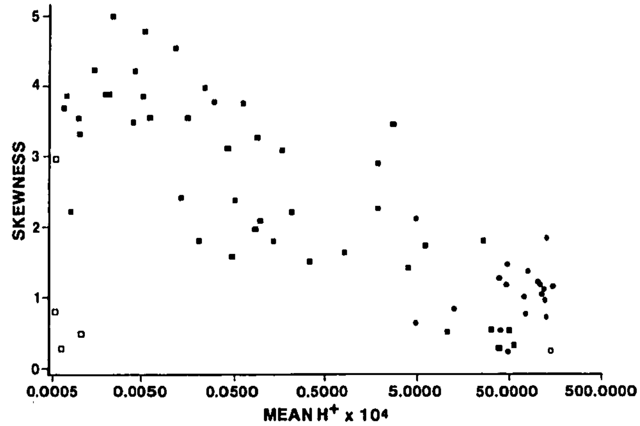

FIG. 3. The positive skewness of the H^+ distributions decreased as mean H^+ increased. The non-antacid groups (circles) had high mean H^+ and slightly positively skewed distributions, and the antacid groups (squares) had the lower mean H^+ with more positively skewed distributions. (The open squares and circles represent groups of obese patients.)

References

1. Giesecke AH Jr: Averaging values for gastric *p*H incorrect. ANESTHESIOLOGY 50:70–71, 1979
2. Krause PD: Statistical analysis of pH data. Anesth Analg 57:143–144, 1978
3. Giesecke AH, Beyer CW, Kallus FT: More on interpretation of pH data. Anesth Analg 57:379–381, 1978
4. Pace NL, Ohmura A, Mashimo T: Averaging *p*H *vs.* H^+ values. ANESTHESIOLOGY 51:481–482, 1979
5. Drummond GB: More on calculation of mean pH values. Anesth Analg 58:63, 1979
6. Kamaya H, Mashimo T, Ueda I: *p*H average rebuttal. ANESTHESIOLOGY 52:449–450, 1980
7. Feinstein AR: On central tendency and the meaning mean for pH values. Anesth Analg 58:1–3, 1979
8. Ueda I, Eyring H: Hydrogen ion concentration vs. pH. Anesth Analg 58:487–490, 1979
9. Manchikanti L, Rousch JR: Effect of preanesthetic glycopyrrolate and cimetidine on gastric fluid pH and volume in outpatients. Anesth Analg 63:40–46, 1984
10. Manchikanti L, Marrero TC, Rousch JR: Preanesthetic cimetidine and metoclopramide for acid aspiration prophylaxis in elective surgery. ANESTHESIOLOGY 61:48–54, 1984
11. Manchikanti L, Colliver JA, Marrero TC, Rousch JR: Ranitidine and metoclopramide for prophylaxis of aspiration pneumonitis in elective surgery. Anesth Analg 63:903–910, 1984
12. Manchikanti L, Colliver JA, Rousch JR, Canella MG: Evaluation of ranitidine as an oral antacid in outpatient anesthesia. South Med J 78:818–822, 1985
13. Manchikanti L, Grow JB, Colliver JA, Hadley CH, Hohlbein LJ: Bictra (sodium citrate) and metoclopramide in outpatient anesthesia for prophylaxis against aspiration pneumonitis. ANESTHESIOLOGY 63:28–34, 1985
14. Manchikanti L, Colliver JA, Marrero TC, Rousch JR: Assessment of age-related acid aspiration risk factors in pediatric, adult, and geriatric patients. Anesth Analg 64:11–17, 1985
15. Manchikanti L, Colliver JA, Canella MG, Hohlbein LJ: Assessment of effect of various modes of premedication on acid aspiration risk factors in outpatient surgery. Anesth Analg 66:81–84, 1986
16. Manchikanti L, Colliver JA, Grow JB, DeMeyer RG, Hadley CH, Rousch JR: Dose-response effects of intravenous ranitidine on gastric *p*H and volume in outpatients. ANESTHESIOLOGY 65:44–49, 1986
17. Manchikanti L, Rousch JR, Colliver JA: Effect of preanesthetic ranitidine and metoclopramide on gastric contents in morbidly obese patients. Anesth Analg 65:195–199, 1986