RISKS OF USING BEDSIDE TESTS TO VERIFY NASOGASTRIC TUBE POSITION IN ADULT PATIENTS

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ABSTRACT

Nasogastric (NG) tubes are commonly used for enteral feeding. Complications of feeding tube misplacement include malnutrition, pulmonary aspiration, and even death. We built a Bayesian network (BN) to analyse the risks associated with available bedside tests to verify tube position. Evidence on test validity (sensitivity and specificity) was retrieved from a systematic review. Likelihood ratios were used to select the best tests for detecting tubes misplaced in the lung or oesophagus. Five bedside tests were analysed including magnetic guidance, aspirate pH, auscultation, aspirate appearance, and capnography/colourimetry. Among these, auscultation and appearance are non-diagnostic towards lung or oesophagus placements. Capnography/colourimetry can confirm but cannot rule out lung placement. Magnetic guidance can rule out both lung and oesophageal placement. However, as a relatively new technology, further validation studies are needed. The pH test with a cut-off at 5.5 or lower can rule out lung intubation. Lowering the cut-off to 4 not only minimises oesophageal intubation but also provides extra safety as the sensitivity of pH measurement is reduced by feeding, antacid medication, or the use of less accurate pH paper. BN is an effective tool for representing and analysing multi-layered uncertainties in test validity and reliability for the verification of NG tube position. Aspirate pH with a cut-off of 4 is the safest bedside method to minimise lung and oesophageal misplacement.

Keywords: Decision analysis, Bayesian networks, nasogastric tube, patient safety.

INTRODUCTION

At least one million nasogastric (NG) feeding tubes are purchased by the National Health Service in England each year. Complications of feeding tube misplacement include malnutrition, pulmonary aspiration, and even death. For blind insertion, the rate of respiratory placement is typically 1-3%. Inadvertent tube placement in the oesophagus was observed in 19 out of 100 blind NG tube insertions.[1] Reported rates of tube misplacement on insertion and tube migration after correct initial placement vary between 1.3% and 50% in adults.[2]

There is a distinct lack of consensus as to the optimum method of checking the feeding tube position. In response to several deaths directly related to NG tube misplacement, the National Patient Safety Agency (NPSA) in England issued safety alerts in February 2005 to describe correct procedures for checking the position of feeding tubes.[3,4] However, additional cases of death due to NG tube misplacement have been reported since the circulation of these alerts. Possible reasons include the use of inappropriate checking procedures or the misinterpretation of radiographs by clinicians. Also documented are the life-threatening complications from enteral formulations or medications entering the lung through a misplaced NG tube, i.e. 'aspiration-by-proxy', that did not result in patient harm.[5] The most recent safety guideline forbids the use of auscultation ('the whoosh test'), while recommending testing of the tube aspirate pH

(cut-off 5.5) and the use of chest radiographs whenever necessary.[6]

The task to correctly position a blindly inserted NG tube is challenging because none of the bedside procedures can provide definitive verification of tube position. Even the current gold standard of a chest radiograph is prone to misinterpretation. We were commissioned by NPSA to review the safety of using bedside methods to verify NG tube position with an emphasis on confirming initial tube placements prior to feeding.

METHODS

A Bayesian network (BN) was constructed to analyse risks in safe feeding. BNs are graphical tools for reasoning with uncertainties.[7-9] They can be viewed as a special knowledge network that captures one's beliefs in a risky decision. Each node (circle) represents an uncertain event; each arrow (or edge) represents dependence between two events, and the lack of arrow indicates conditional independence. The structure of a BN reflects how we think different events relate to each other. The numerical part of a BN in the form of conditional probabilities reflects the strength of such dependence. In the case of NG tube positioning, the tube site is the shared parent node of different bedside tests. Arrows pointing out from tube site and into the bedside tests indicate our belief that the outcome of these tests depend, among other things, on the location of the feeding tube which could be lung, intestine, stomach, or oesophagus. No arrows, however, link different tests together because we believe that the outcome of one test (its findings) does not depend on those of another test (conditional independence). For aspirate pH, feeding and medication history of a patient were modelled as additional parents of the pH test; pH paper was modelled as a child of pH meter (which is a child of tube site). This allows us to examine test results from various combinations of feeding and medication conditions, as well as to test using a less reliable measurement of pH.

We capture the risk of tube misplacement during initial insertion (i.e. before checking) in the prior distribution of the tube sites. Test validity (i.e. sensitivity and specificity) was incorporated as conditional probability of a finding in each tube site. Once a finding has been entered into the BN, the prior distribution will be updated according to the Bayes' rule. The result is the posterior distribution of the tube sites that reflects one's revised belief about the location of the NG tube in light of the finding. We built the BN in software Netica®.

Information on test validity was retrieved from a systematic review in which chest X-rays served as the gold-standard. Multiple sources of information on the same test were combined by a simple weighted average, based on sample size. Missing information was dealt with by assuming a flat distribution where all the findings were assumed to be equally likely. For aspirate pH, raw data were kindly provided by the author (Prof Norma Metheny).[10-16] This enabled a detailed study of the influence of antacid medication and feeding status of a patient, as well as measurement methods such as Baxter paper versus pH meter. We generally assume that the tube had 20%, 50%, 20%, and 10% probabilities of being inserted into the lung, stomach, oesophagus, and small bowel, respectively.[1,2] We also tested scenarios of low initial risks (prior probabilities of lung/stomach/oesophagus/small bowel =10%/80%/10%/0%) and high initial risks (prior =30%/35%/25%/10%) where tube misplacements were respectively 30% and 65% of the time, compared to 50% of the time, as widely assumed. The likelihood of safe feeding varies with tube site. The consequences of feeding into a misplaced tube in the lung are the most severe, followed by oesophagus, and small bowel. We used likelihood ratios (LRs) to prioritise safety needs. LR_1, LR_2, and LR_3 measured the capacity of a test to detect tubes in the lung, oesophagus, and small bowel in contrast to the stomach (the correct tube site).(*)

$LR_1 = p(\text{finding}|\text{not lung}) / p(\text{finding}|\text{lung})$

$LR_2 = p(\text{finding}|\text{stomach}) / p(\text{finding}|\text{oesophagus})$

$LR_3 = p(\text{finding}|\text{stomach}) / p(\text{finding}|\text{small bowel})$

Two types of findings are worth noting. Infinite LR_1, LR_2, and LR_3 indicate that lung, oesophagus, and small bowel misplacements are ruled out, in which case feeding can safely start. An example is the finding of a stomach tube using correctly interpreted chest X-rays, the current gold-standard. Secondly, zero LRs would confirm the lack of safety as the tube is in the lung (LR_1) or outside the stomach (LR_2 and LR_3). This happens when a lung tube is found by correctly interpreted chest X-rays. Note that under the assumption of conditional independence, the utility of several tests, when used

together to verify tube site, was simply the product of their respective LRs.

RESULTS

Aspirate pH,[10-13,16] appearance,[11] auscultation,[10,17] capnography/colourimetry,[11] and magnetic guidance[18] emerged from our literature review as existing or potential bedside tests for locating blindly inserted NG tubes. The BN is shown in Figure 1. Contained within each bedside test are its findings; next to each finding is the joint (average) probability of observing the finding given the test validity (Table 1(**)) and the prior probabilities that the tube is inserted into the lung, stomach, oesophagus, and small bowel, respectively (i.e. 20%, 50%, 20%, and 10%; Figure 1). Note that we included the discredited auscultation test in our analysis, for two reasons: firstly to provide a check on the validity of model predictions and secondly, to analyse its potential when used in combination with other tests. For the aspirate pH, we chose 4.0, 5.0, 5.5, and 6.0 as the cut-offs (findings). Table 1 presents the combined (averaged) sensitivity of each finding of each test. The pH from oesophageal intubation was extrapolated from studies on reflux patients, which together demonstrate that the median percentage time with oesophageal pH measured <4.0, is between 0.5-3.1% of recorded 24-hour periods in healthy individuals;[19-24] sensitivity of the pH test above 4 was assumed to be evenly distributed. A lack of high-quality evidence for auscultation test also led us to assume that the loudest sound was equally likely to be heard in epigastrium, left upper quadrant (LUQ), and right upper quadrant (33% in each case) through lung tubes.

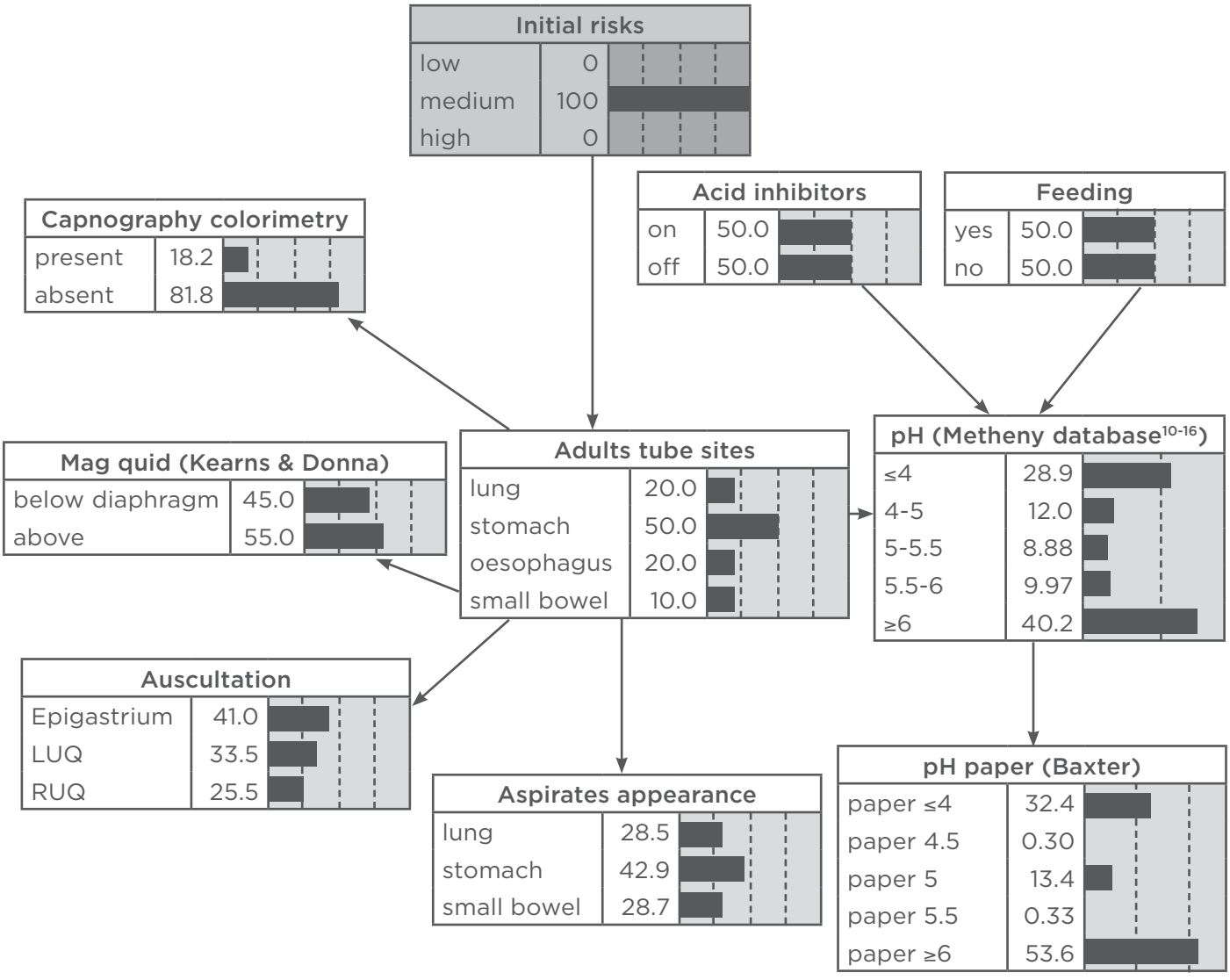

Figure 1: The Bayesian Network model for the safe verification of nasogastric tubes.
LUQ/RUQ: left/right upper quadrant.

Table 1: Sensitivity of the bedside tests in positioning blindly inserted NG tubes.

Test	Findings	Lung	Stomach	Oesophagus	Small Bowel
pH Meter	≤4	0.00	54.60%	5.00%	6.26%
	≤5	0.00	67.80%	30.00%	10.13%
	≤5.5	0.00	75.23%	55.00%	11.80%
	<6	0.36%	84.51%	80.00%	14.38%
	≥6	99.60%	15.50%	20.00%	85.60%
Auscultation	Epigastrium	33.30%	29.20%	62.00%	73.60%
	LUQ	33.30%	41.60%	19.00%	22.40%
	RUQ	33.30%	29.20%	19.00%	4.00%
Appearance	Lung	46.10%	21.20%	33.30%	20.00%
	Stomach	26.90%	57.60%	33.30%	20.00%
	Small bowel	26.90%	21.20%	33.30%	60.00%
Capnography	CO_2 present	89.30%	0.40%	0.40%	0.40%
	CO_2 absent	10.70%	99.60%	99.60%	99.60%
Magnetic Guidance	Below diaphragm	0.00	75.00%	0.00	75.00%
	Above diaphragm	100.00%	25.00%	100.00%	25.00%

NG: nasogastric; LUQ/RUQ: left/right upper quadrant.

Table 2: The effectiveness of the bedside tests to rule out lung and oesophagus (infinite LRs).

Test	Findings	LR_1	LR_2	LR_3
pH	≤4	Infinite	10.92	8.72
	≤5	Infinite	2.26	6.69
	≤5.5	Infinite	1.37	6.38
	<6	207.22	1.06	5.88
	≥6	0.26	1.29	0.18
Auscultation	epigastrium	1.29	0.47	0.40
	LUQ	1.01	2.19	1.86
	RUQ	0.71	1.54	7.30
Appearance	lung	0.52	0.64	1.06
	stomach	1.74	1.73	2.88
	small bowel	1.08	0.64	0.35
Capnography	CO_2 present	0.004	1.00	1.00
	CO_2 absent	9.31	1.00	1.00
Magnetic guidance	below diaphragm	Infinite	Infinite	1.00
	above diaphragm	0.44	0.25	1.00

LRs: likelihood ratios; LR_1: p(finding|not lung)/p(finding|lung); LR_2: p(finding|stomach)/p(finding|oesophagus); LR_3: p(finding|stomach)/p(finding|small bowel); LUQ/RUQ: left/right upper quadrant.

Table 2[**] presents the LRs based on test validity (Table 1) and the prior. A quick scan of Table 2 shows that the best tests to detect lung intubation, as indicated by an infinite LR_1, are pH (5.5 or lower) or magnetic guidance (below diaphragm), and the best tests to detect oesophageal intubation, as indicated by an infinite LR_2, are magnetic guidance (below diaphragm), followed by aspirate pH with a cut-off at 4. The latter can reduce the chance of oesophagus placement relative to stomach placement by nearly 10-fold (LR_2=10.92). In contrast, the chance of oesophagus placement would barely change when a pH of 5.5 or less is observed (LR_2=1.37).

Using the BN model in Netica, a pH of 5.5 or less would predict the probabilities of lung, stomach, oesophagus, and small bowel placements are 0%, 75.5%, 22.1%, and 2.37% respectively, in contrast to the initial 20%, 50%, 20%, and 10%. A pH of 4.0 or less would predict the probabilities of lung, stomach, oesophagus, and small bowel placements are 0%, 94.4%, 3.46%, and 2.16%, respectively. That is, a pH at 4 or less reduces the risk of oesophageal intubation from 20% to 3.46%, i.e. from fairly uncertain to 'beyond reasonable doubt'.

Auscultation and appearance are not useful on their own as their LRs clustered around 1. The only finding useful in terms of lung and oesophagus intubations is the auscultation test which found the loudest sound heard in the LUQ (LR_2=2.19). This would halve the chance of oesophageal placement (from 20% to 11.3%) relative to stomach placement (from 50-62.1%). Using capnography or colourimetry, detecting CO_2 would increase the chance of lung tubes from 20-98% (LR_1=0.004). However, the absence of CO_2 cannot be taken as definitive evidence that the tube is outside the lung (LR_1 =9.31), and the revised belief of lung placement is 2.62%.

Feeding, Antacid Medication, and Measurement Technique Effects on pH Test

Recent feeding, administration of antacid therapy, or using pH paper instead of meter to measure pH, all reduce sensitivity of the pH test. Given a pH of 5.5 or less, receiving antacids would increase the chance of oesophagus placement from 22.1-23.6%, though feeding had little impact. Given the finding of a pH of 4.0 or less, receiving antacids would increase the chance of oesophagus placement from 3.46-4.05% and further to 4.20% if the patient has recently been fed. If Baxter paper is used instead of pH, the reading of 4 or less would predict the probabilities of stomach, oesophagus, and small bowel placements to be 89.2%, 8.49%, and 2.30%, whereas a reading of 5.5 or less would predict the probabilities of lung, stomach, oesophagus, and small bowel placements to be 0.024%, 78%, 19.6%, and 2.41%.

Impact of Low or High Initial Risks on pH

If a pH of 4 or less was observed, the predicted probabilities of lung, stomach, oesophagus, and small bowel placements were respectively 0%, 98.9%, 1.13%; 0% under low level of initial risks; and 0%, 91.1%, 5.96%, and 2.98% under high level of initial risks. If a pH of 5.5 or less was observed, the chances of lung, stomach, oesophagus, and small bowel placements were 0%, 91.6%, 8.37%, and 0% likely under low level of initial risks and 0%, 63.8%, 33.3%, and 2.86% likely under high level of initial risks.

Assume a worst case scenario where the initial insertions have a high risk of misplacements and the verification is done by Baxter paper instead of pH meter. A finding of a pH of 5.5 or less would predict lung, oesophagus, and small bowel misplacements to be 0%, 54.6%, and 2.03% respectively, whereas a pH of 4 or less would predict the probabilities of lung, oesophagus, and small bowel misplacements to be 0%, 8.49%, and 2.30%, respectively. That is, if a patient is fed after a pH of 5.5 or less is observed in the worst case scenario, then half of the time the feeding would be in the oesophagus instead of the stomach.

DISCUSSION

Five bedside tests were investigated, i.e. magnetic guidance, aspirate pH (with cut-offs 4, 5, 5.5, and 6), auscultation, aspirate appearance, and capnography/colourimetry. Consistent with the existing literature and the recommendation of NPSA, neither auscultation nor aspirate appearance can be recommended for use on their own to detect tube misplacements in the lung or oesophagus. It is worth noting that if capnography/colourimetry is used, the absence of CO_2 cannot be taken as evidence for safe feeding (outside the lung) because such findings are observed in 10.7% of the lung placements (Table 1). The safest tests are magnetic guidance and pH of tube aspirate. Magnetic guidance can rule out lung or oesophageal placement – the two most hazardous potential tube

sites, whereas a pH test with cut-offs at 5.5 or lower can rule out lung misplacements. Further lowering the cut-off to 4 or less would minimise oesophagus misplacements. Magnetic guidance is a relatively new technology and has a relatively small, though growing, evidence base (n=243).

Magnetic guidance has been studied in adults and children, particularly in the context of post-pyloric feeding with retrospective studies.[25-27] More recent prospective studies indicate encouraging accuracy of the technique[28] but there are additional costs of technical equipment and devices required for every tube placement[29] and the process does not eliminate the risk of adverse soft tissue injury.[30] Further validation studies are needed.

The pH test of tube aspirates is widely used, well-studied, and has an established evidence base (nearly 800 cases in our database). Current practice also recommends the use of aspirate pH, though with a cut-off of 5.5. Our analysis shows lowering the pH cut-off from 5.5 to 4.0 can enhance safety in oesophageal intubations. Furthermore, the use of Baxter paper, feeding, medication history of a patient, and potential variations in the risks in the initial insertions of the tube, means a lower pH would provide an extra layer of safety for reducing oesophageal feeding. Lowering the pH threshold would result in more patients with tubes correctly placed in the stomach to be sent for X-rays (unnecessary X-rays). It is therefore a trade-off that needs careful assessment: minimising placement errors (mainly in the oesophagus) versus minimising unnecessary X-rays. Consider three strategies in Table 3, i.e. X-ray all patients, X-ray only patients with pH higher than 5.5, or X-ray only patients with pH higher than 4. Under the assumption of 50% initial insertion errors, adopting a pH with a cut-off of 4 would reduce placement errors from 9.38% to 0.62% whilst increasing unnecessary X-rays from 24.15-34.05% (Table 3).

Table 3: Outcomes of clinical guidelines.

	Placement Errors	Unnecessary X-ray
pH ≤5.5 feed; X-ray everyone with pH>5.5	9.38%	24.15%
pH ≤4 feed; X-ray everyone with pH>4	0.62%	34.05%
X-ray everyone	0	75%

One criticism of our recommendation of lowering the pH cut-off is that X-ray facilities are not widely available and therefore lowering the pH may lead to feeding delays and potential harm from lack of nutrition.[6] Another criticism surrounds the liability of chest radiographs to be misinterpreted. Reducing the pH cut-off used for tube aspirate pH testing may expose patients to a risk of inadvertent feeding if the consequent increase in radiographs to check tube position is associated with an accompanying increase in X-ray misinterpretation. This is debatable as misinterpretation of radiographs affects a cohort of patients with a tube aspirate pH between 4.0 and 5.5. Using the current guideline with a higher pH cut-off (5.5), all of these patients will be fed through the tube regardless of the actual tube site. Given a constant rate of tube misplacement, it is not possible to increase the number of inadvertent feeding errors using a lower pH cut-off, regardless of the risk of X-ray misinterpretation.

In terms of using multiple tests instead of a single test, consider safety needs to rule out lung and oesophagus placements. Magnetic guidance can achieve both ends on its own; the best test to be used with aspirate pH is one that is sensitive to oesophageal misplacement. Auscultation has the potential to halve the chance of oesophagus placement, but the method is subject to interpretation errors and is therefore unreliable.

CONCLUSIONS

The key to maximising the safety of NG tube feeding is to rule out feeding into the lung and to minimise feeding into the oesophagus. A critical step to prevent inadvertent administration of enteral feed into the bronchopulmonary tract is reliable confirmation of tube position prior to commencing feeds. There is also the potential for soft tissue trauma caused during incorrect tube insertion. A recent study reports 35 (18.7%)

incidents of pneumothorax among 187 tube misplacements with an associated increase in mortality.[31] Techniques to improve the accuracy of feeding tube insertion such as electromagnetic guidance may prevent both pulmonary tree injury and the consequences of tube malposition. Considering the strength and reliability of available evidence, this research demonstrates the potential of magnetic guidance testing to be the safest option, followed by the pH test with a cut-off of 4.0 or 5.5. A higher cut-off of pH should only be used when the clinicians have an excellent track record and the pH is measured accurately. Overall, the pH test is the safest test when using a cut-off of 4.0.

Footnotes

(*) The conditional probability of a negative finding (e.g. not lung) is the joint probability of the finding and not lung divided by the prior probability of not lung: p(finding|not lung) = (p[finding & stomach]+p[findings & oesophagus]+p[findings & small bowel])/(p[stomach]+p[oesophagus]+p[small bowel]), where p(finding & tube site) = p(finding|tube site)*p(tube site).

(**) The pH findings were defined differently in the BN than in Tables 1 and 2. The BN software (Netica) rendered it impossible to present pH values in terms of cut-offs, e.g. lower or higher than 5.5. We therefore expressed the pH as discrete categories, i.e. ≤4, between 4 and 5, between 5 and 5.5, between 5.5 and 6, and ≥6. In Tables 1 and 2 the probabilities were binary based on the pH cut-off which is how the test is used in reality. These two methods of expression were consistent. p(pH≤cut-off) is the sum of the discrete probabilities accumulated until that cut-off and the p(pH>cut-off) = 1-p(pH≤cut-off).

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