Tracheal pH monitoring and aspiration in acute stroke

JOANNE CLAYTON1, CATHERINE I. A. JACK2, CHRISTOPHER RYALL2, JANE TRAN3, EMAD HILAL3, MARGOT GOSNEY1

1Department of Geriatric Medicine, University of Liverpool, Liverpool, Merseyside, UK
2Elderly Medicine & Radiology, Royal Liverpool and Broadgreen University Hospitals NHS Trust, Liverpool, Merseyside, UK
3Pulmonary function, CTC, Liverpool NHS Trust, Broadgreen Hospital, Merseyside, UK

Address correspondence to: J. Clayton, Speech and Language Therapy Department, Royal Liverpool Hospital, Prescot Street, Liverpool, L7 8XP, UK. Tel: (+44) 151 706 2700. Email: Joanne.Clayton@rlbuht.nhs.uk

Abstract

Background: aspiration can lead to chest infections, increased morbidity and mortality in stroke sufferers. It is important clinically and for research purposes to identify all patients who aspirate. At present, videofluoroscopy is the gold standard for detecting aspiration. The aim of this study was to investigate aspiration in acute stroke patients, who are safe for oral intake as assessed by bedside swallow test and videofluoroscopy, using tracheal pH monitoring.

Methods: thirty-four stroke patients admitted to the Acute Stroke Unit gave informed consent and underwent tracheal pH monitoring 4–19 days post-stroke. A standardised acid meal was served.

Results: two traces were discarded. Nine of the 32 remaining studies showed a drop in tracheal pH <5.5 following ingestion of an acidic meal. Two patterns of lowered tracheal pH were observed: three cases showed a prolonged fall in pH to <5.5, which took over 15 minutes to return to baseline and six had acute falls in pH to <5.5, which rapidly recovered in under 4 minutes. In six the drop occurred immediately after the meal, and in three a delay was observed prior to the drop.
Conclusion: tracheal acidification, which could represent aspiration, has been observed in 9 of 32 stroke patients assessed as safe to take diet and fluids orally by bedside assessment and videofluoroscopy. This is a preliminary investigation that provides information about tracheal pH monitoring in acute stroke patients.

Keywords: aspiration, diagnostic studies, dysphagia, elderly, pH monitoring, stroke

Background
Stroke is the greatest single cause of neurogenic dysphagia in adults [1–3] and can lead to aspiration of food, drinks and oral–pharyngeal secretions into the lungs. Aspiration pneumonia is an important complication of stroke that can even result in death [4, 5]. It is important clinically and for research purposes that all patients who aspirate be correctly diagnosed.

Many bedside assessments exist to detect swallowing disorders, but none can identify all patients who aspirate. At present, videofluoroscopy is the best method for detecting aspiration and silent aspiration at every stage of the swallow, and reliability is high [6, 7]. There are limitations, however: positioning of patients may not reflect how they are fed on the ward, screening time is limited due to radiation exposure and consistencies are not standardised [8] or do not reflect those taken on the wards [9], among others.

Tracheal pH monitoring is a sensitive technique for detecting acid aspiration into the trachea [10]. It is a simple and nonhazardous technique [11] that allows a continuous trace to be collected with the patient undergoing normal activities on the ward. Consistencies consumed and positioning during meals reflect those actually experienced by the patient under real circumstances.

Study aim and hypothesis
The primary aim of this study is to investigate tracheal acidification, which could represent aspiration, in acute stroke patients who have been assessed as safe to take diet and fluids orally by bedside swallow test and videofluoroscopy.

The research hypothesis to be tested is that acute stroke patients are at risk of aspirating small amounts of acidic food and drinks below the vocal cords, which can be measured by changes in pH in the trachea.

Methods
Setting
The trial was conducted on the Acute Stroke Unit at the Royal Liverpool University Hospital. The study gained ethical approval from the Liverpool Research Ethics Committee and the Royal Liverpool and Broadgreen University Hospitals (RLBUH) Research and Ethics Committee. Financial support was provided by Health Research & Development North West.

Inclusion criteria
- Diagnosis of acute stroke on the basis of the clinical findings and CT scan to exclude other possible diagnoses.
- No history of oral, pharyngeal or oesophageal dysphagia prior to the stroke.
- No history of gastric disorders, surgery or medication.
- Able to give informed consent.
- Between 4 and 21 days post-stroke.

Exclusion criteria
- Severe illness.
- Patients assessed as Nil By Mouth.
- Participation in other research studies being undertaken on the same population.
- Non-English speaker.
- Patients unable to sit in a chair for videofluoroscopy.
- Impaired mental function, measured on the Mini-Mental State Examination [12].
- Declined.
- Presence of a clinically detectable goitre.

Assessment of swallowing and aspiration
Bedside assessment of swallowing was carried out by a qualified speech and language therapist and reflected normal hospital procedure. The test included a full oral motor examination, assessment of laryngeal functioning and trial swallows. Some elements of the assessment, such as bolus consistency and volume of barium added, were standardised to help make comparisons more meaningful.

Patients were seated upright in a specially made chair, and assessment was carried out with a lateral view of the oropharynx. Following findings from bedside assessment, patients were assessed with their ‘safest’ consistency first. They then progressed through the range of consistencies (Table 1) to normal or until penetration or aspiration was observed. Aspiration and penetration were recorded using the eight-point scale devised by Rosenbek et al. [13]. During the videofluoroscopy, the tape was watched in real-time and

<table>
<thead>
<tr>
<th>Table 1. Consistency range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Gastro-miro—bottle (normal fluid)</td>
</tr>
<tr>
<td>2. Resource thickened drink pot (114 g)—syrup + 1 tablespoon barium</td>
</tr>
<tr>
<td>3. Resource thickened drink pot (114 g)—custard + 1 tablespoon barium</td>
</tr>
<tr>
<td>4. Forti-pudding pot + 1 tablespoon barium</td>
</tr>
<tr>
<td>5. Bread—coated with barium paste</td>
</tr>
<tr>
<td>6. Biscuit—coated with barium paste</td>
</tr>
</tbody>
</table>
a consensus was reached between the researcher and the radiologist before the score was recorded. Mealtime recommendations reflected those consistencies where no penetration or aspiration was observed on videofluoroscopy. Any patient who aspirated on all consistencies was referred for non-oral feeding and excluded from the project.

Tracheal pH was recorded using a Medtronic Synectics microSleep Digitrapper, which was recalibrated to pH 1 and 7 before each study as per the manufacturer’s guidelines [14]. Using a 13 gauge Wallace cannula, a paediatric antimony electrode was inserted, under local anaesthetic, into the trachea via the cricothyroid membrane [11]. The electrode sits approximately 5 cm below the larynx in the trachea. Tape was used to secure the probe, and a small sterile dressing was applied. Monitoring occurred with the patient taking what was perceived to be a safe diet. Each patient was offered a choice of acidic drinks and had an evening meal consisting of the food items listed in Table 2. Meals and drinks were modified to the appropriate consistency for each patient. Drinks were taken with the meal or following a period of rest, if swallowing assessment revealed fatigue. Patients were encouraged to finish the meal and/or a (200 ml) drink in one sitting. Additional acidic and nonacidic drinks were given at the patient’s request. The nursing staff and researcher kept a diary of patient activity and oral intake.

When recording was complete the researcher removed the probe and the data was downloaded onto the Medtronic Synectics Polygram function testing software for Windows (version 2.05). Owing to limitations in the software, both meals and drinks were labelled with the ‘knife and fork’ symbol on the computer trace. The clinical physiologist, who was blinded to the results of the videofluoroscopy and the clinical condition of the patient, examined the traces and classified the patients as aspirators or nonaspirators. Aspiration was defined as a drop in tracheal pH to <5.5 [15, 16]. Measurements of pH were taken from the trace every 30 seconds for half an hour before and after the meal/drink that was ‘aspirated’, and the mean values are calculated for each. The minimum pH value post-meal and the length of time the trace remained below pH 5.5 were recorded. In patients classed as nonaspirators, measurements were taken before and after the meal. Tracheal pH monitoring, bedside assessment and videofluoroscopy were all performed within 24 hours. Initially, the researcher aimed to leave the tracheal pH probe in place for 24 hours; however, many patients expressed concern about sleeping with it in situ. In view of this, subjects were given the option of having the probe removed before bed or at their request. The total length of monitoring was recorded (Table 3).

Statistics
Data were analysed using SPSS 10.0 for Windows. To describe patient characteristics, the mean, standard deviation, median and range were employed. The mean, standard deviation, 95% confidence intervals and histograms were used to analyse the distribution of the variables.

To test within group changes, the paired samples t-test and the Wilcoxon test were used. Between group differences were assessed using the independent samples t-test and the Mann–Whitney U test.

Results
Thirty-four individuals completed the study and underwent tracheal pH monitoring; however, two traces had to be discarded. The first was invalid because the surface electrode on the patient’s chest was dislodged and the second because the written record of oral intake was missing. Furthermore, contrary to previous findings that stated that tracheal pH monitoring is ‘a simple and nonhazardous technique’ [10], the

Table 2. List of food items and their pH values

<table>
<thead>
<tr>
<th>Food/drink</th>
<th>pH value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh orange juice</td>
<td>3.85</td>
</tr>
<tr>
<td>Fresh apple juice</td>
<td>3.72</td>
</tr>
<tr>
<td>Fresh cranberry juice</td>
<td>3.13</td>
</tr>
<tr>
<td>Lemon barley: water</td>
<td></td>
</tr>
<tr>
<td>1 : 4</td>
<td>2.48</td>
</tr>
<tr>
<td>1 : 8</td>
<td>2.6</td>
</tr>
<tr>
<td>Lucozade (original)</td>
<td>3.5</td>
</tr>
<tr>
<td>Diet Coke™</td>
<td>4.2</td>
</tr>
<tr>
<td>Tomato soup</td>
<td>4.32</td>
</tr>
<tr>
<td>Sweet and sour sauce (± chicken)</td>
<td>3.3</td>
</tr>
<tr>
<td>Tinned fruit salad in apple juice</td>
<td>3.86</td>
</tr>
</tbody>
</table>

Table 3. Subject information

<table>
<thead>
<tr>
<th>Patient details</th>
<th>Description of sample (n = 32)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demography</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>22 (69%)</td>
</tr>
<tr>
<td>Female</td>
<td>10 (31%)</td>
</tr>
<tr>
<td>Age [mean (SD)]</td>
<td>71.09 (10.95) (minimum 44, maximum 89)</td>
</tr>
<tr>
<td>Stroke history</td>
<td></td>
</tr>
<tr>
<td>Stroke type</td>
<td></td>
</tr>
<tr>
<td>LACS</td>
<td>12 (38%)</td>
</tr>
<tr>
<td>PACS</td>
<td>9 (28%)</td>
</tr>
<tr>
<td>TACS</td>
<td>9 (28%)</td>
</tr>
<tr>
<td>POCS</td>
<td>2 (6%)</td>
</tr>
<tr>
<td>Affected hemisphere</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>16 (50%)</td>
</tr>
<tr>
<td>Left</td>
<td>16 (50%)</td>
</tr>
<tr>
<td>Days post-stroke (median)</td>
<td>10 (minimum 4, maximum 19)</td>
</tr>
<tr>
<td>Tracheal pH monitoring</td>
<td></td>
</tr>
<tr>
<td>Hours monitored (median)</td>
<td>12.5 (minimum 3, maximum 21)</td>
</tr>
<tr>
<td>Number of meals/drinks consumed (median)</td>
<td>3 (minimum 1, maximum 6)</td>
</tr>
<tr>
<td>Measurements of function</td>
<td></td>
</tr>
<tr>
<td>SSS [mean (SD)]</td>
<td>42 (11.5) (minimum 19, maximum 58)</td>
</tr>
<tr>
<td>MMSE: [mean” (SD)]</td>
<td>26 (3.5) (minimum 20, maximum 30)</td>
</tr>
<tr>
<td>Barthel index [mean (SD)]</td>
<td>13 (5.5) (minimum 2, maximum 20)</td>
</tr>
</tbody>
</table>

Stroke types were classified according to the Oxford Community Stroke Project system: LACS, lacunar stroke; PACS, partial anterior circulating infarct; POCS, posterior circulation infarct; TACS, total anterior circulating infarct [21]. MMSE, Mini-Mental State Examination; SSS, Scandinavian Stroke Scale.

*Missing values (n = 26).
procedure was abandoned in four patients due to difficulty placing the probe; in three who felt faint and in one who found the process uncomfortable. In contrast, those who completed the study tolerated the probe well, cough being the only discomfort reported. Patient details and a description of the study sample are shown in Table 3.

**Pattern of changes**

Visual inspection of the traces revealed evidence of tracheal acidification (defined as a drop in tracheal pH <5.5) in nine patients following ingestion of acidic food or drinks. Two patterns of lowered tracheal pH were observed: three cases showed a prolonged fall in pH to <5.5, which took over 15 minutes to return to baseline, and six subjects had acute falls in pH to below 5.5, which rapidly recovered in under 4 minutes (Figure 1). Figure 2 is a graph showing the number of aspirators and nonaspirators within the various clinical categories of interest. Although the numbers were very small, the following patient characteristics appeared to be associated with the prolonged-fall subgroup (n = 3): age ≥70 years, penetration/aspiration observed on videofluoroscopy, oropharyngeal dysphagia present, male and left hemisphere cardiovascular accident. The acute-drop subgroup did not appear to be strongly associated with any particular categories. It was interesting that patients with prolonged tracheal pH changes all had abnormal findings on both bedside and videofluoroscopic assessments. In contrast, acute pH drops occurred in the presence of normal and abnormal findings on both bedside and videofluoroscopic tests, and some patients with abnormal findings on bedside and videofluoroscopy had no change in tracheal pH (n = 13).

In six individuals, drops in tracheal pH were observed immediately following the acid meal; however, in three, a delay was observed prior to the drop (onset 8, 17 and 25 minutes post-meal).

**Magnitude of change**

There was no significant difference in mean pH scores between the aspirator and nonaspirator groups (P = 0.1) before the acid meal; however, patients in the aspirator group did have a lower mean pH score (pH 5.91) than nonaspirators (pH 6.47) after the acid meal. There was a difference of –0.08 in mean pH score before and after the acid meal for the nonaspirator group and a difference of –0.39 in mean pH score before and after acid meal for the aspirator group. The difference between the two groups in mean pH score was –0.31 (95% CI –0.52, –0.11). Changes in mean pH score were more varied in the aspirator group as shown in Figure 3. This variability was due to differences in the timing and duration of acute (under 4 minutes) versus chronic (over 15 minutes) drops in pH within the aspirator group. Acute drops in pH lasting <1 minute (n = 3) had

![Figure 1](image1.png)

Figure 1. Photographs of tracheal pH traces from two stroke subjects classified as ‘aspirators’ following visual inspection of the traces. The first trace demonstrates a prolonged fall in pH <5.5 following acid meal. The second photograph shows an acute drop in pH <5.5 following acid meal that quickly returned to baseline. The meal symbol represents food and/or drinks.
little influence on the mean pH score measured over 30 minutes.

**Discussion**

The definition of tracheal acidification is poorly described in the literature. Different studies have used varying cut-off limits to classify tracheal aspiration and some have used the length of the drop in their definition. These figures are arbitrarily assigned and have come from data investigating tracheal acidification in relation to oesophageal reflux in a variety of patient groups (asthmatics, cystic fibrosis sufferers and ventilator-dependent children). The data therefore may not be relevant to investigation of tracheal acidification due to aspiration of acidic food and drinks. In this study, the arbitrary measure of tracheal pH <5.5 was used to indicate tracheal acidification and to group patients as aspirators or nonaspirators. The length of the drop was used for subanalysis of the data.

The terms aspirators and nonaspirators were used in this study to differentiate those patients who showed a drop in tracheal pH from those whose pH did not drop below 5.5. These terms were used in a previous study, but although it seems reasonable to assume that a drop in tracheal pH associated with ingestion of acidic food or drinks represents aspiration of this material, there is no scientific proof that the drops actually represent prandial aspiration. It is possible that drops in tracheal pH may be due to gastrooesophageal reflux, technical error or to some other as yet unspecified event. In the current study, there were no acute drops in pH that occurred following intake of nonacidic drinks or before or over 30 minutes after ingesting acidic food and drinks, which supports the hypothesis that the drops in pH are the result of the acid meal and are not due to technical error.

Two patterns of tracheal acidification were seen within the aspirator group: an acute drop in pH <5.5, which returned to baseline in under 5 minutes (n = 6), and a prolonged drop in pH <5.5, which did not rapidly return to baseline (n = 3). The cause of the drop in pH has not been scientifically proven, but it is possible that the acute drops represent aspiration of small amounts of acidic meal that were cleared with an effective cough or were rapidly buffered by tracheobronchial secretions. The prolonged drops in pH may represent those patients who have suffered aspiration of large amounts or those patients whose
protective mechanisms are impaired. Certainly, there may have been some clinical differences between the two subgroups; those patients with prolonged drops in pH were older, had oropharyngeal dysphagia following their stroke and had evidence of penetration and/or aspiration on videofluoroscopy. Another possible explanation is that part of an aspirated bolus adhered to the probe giving extended readings.

The acute-drop subgroup contained two patients with no evidence of dysphagia. Occasional episodes of aspiration occur in normal subjects (we have all experienced the discomfort of violent coughing in response to aspirated material), and it is therefore possible that these were random events. Without a control group of healthy age-matched controls, one can only speculate about ‘normal’ tracheal pH traces. Additionally, it is possible that the probe itself may interfere with the normal swallowing process; research has shown that tracheostomy tubes can cause fixation of the trachea and larynx to the skin, which reduces laryngeal elevation and increases the risk of aspiration [17–19]; however, the pH probe is much smaller (diameter 1.5 mm) in comparison. It is also possible that the acid meal itself may increase the risk of experiencing gastrooesophageal reflux as acidic foods are frequently cited as triggers for heartburn in gastrooesophageal reflux disease (GERD) sufferers; however, this is based on clinical experience and is not well supported in the literature [20].

In three patients, a delay was observed prior to the drop in tracheal pH. This may lead one to question whether the drop was associated with the meal at all. It is possible that the underlying pathology in these cases is different and the changes may reflect aspiration of refluxed gastrooesophageal contents following the meal. Alternatively, the later drops may have been caused by aspiration of material that had been pocketed in the oral cavity, which is common in stroke patients with unilateral facial weakness.

Finally, whilst cricothyroid puncture is a safe procedure, it is invasive and unpopular with patients. It is therefore unlikely to become a routine clinical procedure.

**Future research**

1. It is important that there are studies that investigate the ability of the tracheal pH monitoring technique to detect observed aspiration.
2. There must also be studies that investigate whether the probe has any effect on the swallow process itself.
3. Research into the incidence and prevalence of undiagnosed GERD in acute stroke patients is needed and the effects of ingesting acidic foodstuffs on the incidence of reflux needs to be established.
4. Information about the neutralising effect of saliva and the effect of acidic foodstuffs on saliva would be a useful adjunct to this study.
5. The clinical importance of the findings from tracheal pH monitoring could be established through prospective follow-ups and examination of patient outcomes.

**Key points**

- Videofluoroscopy is the current gold standard for assessing aspiration but it has limitations.
- Tracheal pH monitoring can detect small changes in pH in the trachea, which could represent aspiration.
- pH changes were observed in 9 of 32 patients taking a ‘safe’ diet consistency following videofluoroscopic assessment.
- Videofluoroscopy may not be the gold standard for assessing aspiration.

**References**

Does home treatment affect delirium?  
A randomised controlled trial of rehabilitation of elderly and care at home or usual treatment (The REACH-OUT trial)

GIDEON A. CAPLAN1,2, JANIS COCONIS1, NEVILLE BOARD3, ALLYN SAYERS1, JAN WOODS1

1Post Acute Care Services, Prince of Wales Hospital, Randwick, Sydney, New South Wales 2031, Australia  
2School of Public Health and Community Medicine, University of New South Wales, Sydney, New South Wales 2052, Australia  
3Department of Health, North Sydney, New South Wales 2060, Australia

Address correspondence to: G. A. Caplan. Tel: (+61) 2 9382 2470. Fax: (+61) 2 9382 2477. Email: g.caplan@unsw.edu.au

Abstract

Background: delirium is a frequent adverse consequence of hospitalisation for older patients, but there has been little research into its prevention. A recent study of Hospital in the Home (admission substitution) noted less delirium in the home-treated group.

Setting: a tertiary referral teaching hospital in Sydney, Australia.

Methods: we randomised 104 consecutive patients referred for geriatric rehabilitation to be treated in one of two ways, either in Hospital in the Home (early discharge) or in hospital, in a rehabilitation ward. We compared the occurrence of delirium measured by the confusion assessment method. Secondary outcome measures were length of stay, hospital bed days, cost of acute care and rehabilitation, functional independence measure (FIM), Mini-Mental State Examination (MMSE) and geriatric depression score (GDS) assessed on discharge and at 1- and 6-month follow-up and patient satisfaction.

Results: the home group had lower odds of developing delirium during rehabilitation [odds ratio (OR) = 0.17; 95% confidence interval 0.03–0.65], shorter duration of rehabilitation (15.97 versus 23.09 days; \( P = 0.0164 \)) and used less hospital bed days (20.31 versus 40.09; \( P \leq 0.0001 \)). The cost was lower for the acute plus rehabilitation phases (£7,680 versus £10,598; \( P = 0.0109 \)) and the rehabilitation phase alone (£2,523 versus £6,100; \( P \leq 0.0001 \)). There was no difference in FIM, MMSE or GDS scores. the home group was more satisfied \((P = 0.0057)\).

This study was supported by a grant from the National Demonstration Hospitals Program 3, Commonwealth Department of Health and Ageing. The researchers are independent of the granting body. The granting body did not have the right to review nor did it review the manuscript prior to submission. This article has been prepared following the CONSORT guidelines.