UNIVERSITY OF SOUTHAMPTON

FACULTY OF MEDICINE

School of Health Professions and
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DEVELOPMENT AND EVALUATION OF PREDICTIVE INDICES IN NEUROGENIC DYSPHAGIA

By

Morwenna Jane Collins

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ABSTRACT

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Dysphagia due to neurological disease affects many thousand people in the UK each year. Swallowing difficulties may lead to aspiration of food or drink into the lungs. This aspiration is often 'silent' (unaccompanied by choking, coughing, wheeze or dyspnoea). "Bedside swallowing assessment" in dysphagia is unreliable, even when performed by a trained and experienced clinician. Videofluoroscopy is the 'gold standard' in assessment of dysphagia, but has multiple limitations. A reliable bedside assessment is therefore needed to allow decisions on the safety of oral feeding to be made.

The aim of this thesis was to establish if there is a simple clinical evaluation for aspiration in neurogenic dysphagia. It is likely that aspiration of food or fluid will cause reflex bronchoconstriction and consequential lung volume changes. This will lead to a ventilation perfusion mis-match, hypoxia and ultimately oxygen desaturation.

It further aimed to explore the mechanism of the "swallow / breathe" relationship in neurogenic dysphagia in patients with multiple neurological conditions. A prospective, controlled single blind study was undertaken. Participants were assessed pre and post videofluoroscopy with spirometry and continuously with pulse oximetry during the videofluoroscopy.

43/76 participants were seen to aspirate on videofluoroscopy. Pulse oximetry had a 88.4% sensitivity and 54.5% specificity at detecting aspiration or lack of it. A CHAID analysis was used to develop a sequence fitting algorithm. Using oxygen desaturation, snoring and collar size as variables an 80% sensitivity and 80% specificity was found.

A second study was undertaken observing oxygen saturation while in 10 participants (5 aspirators and 5 non aspirators. It found that aspirating participants destaurate more frequently than non aspirating participants ($p = .008$), for longer periods of time ($p=.008$).

This research further suggests that monitoring of nocturnal oxygen saturation levels, in people who have had stroke may provide a strong indicator of the presence of aspiration or lack of it.

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1.00 CHAPTER ONE: Introduction and literature review - Study 1:

This thesis compares two studies presented separately. The rest of this chapter consists of a review of the literature related to the first study; subsequent chapters describe the method, results and discussion. Chapter five provides the literature review for the second study with further chapters as for the first study. Chapter nine provides the overall conclusions and recommendations.

Introduction:

There is a growing amount of literature discussing the relationship between swallowing and respiration. This is unsurprising as some of the same structures are necessary for both procedures and the pharynx is a shared pathway for both food and air exchange. A high degree of co-ordination is required if these two process events are to co-exist safely. If there is insufficient co-ordination then aspiration of the oral contents into the lungs will occur. Aspiration may lead to choking, pneumonia, sepsis and ultimately death. In this thesis the term "aspiration" denotes food or fluid passing below the level of the true vocal cords into the trachea. Aspiration may be obvious, but in many patients aspiration may occur 'silently' i.e. there are no obvious external indicators that it has happened. It is the latter condition that forms the focus of this thesis.

Members of the health team are frequently required to judge the ability of patients with neurological disease to eat, drink and breathe safely at "the bedside". The importance of the results of such assessment is profound. Failure to detect silent aspiration may have fatal consequences, yet falsely assuming that aspiration is occurring will condemn a patient to remain nil by mouth and all that this entails. It is therefore surprising that very few researchers have investigated the relationships between swallowing and breathing, and fewer still have sought objective measures to assess the co-ordination of swallowing and breathing.

This thesis contains studies in which the researcher attempts to develop further understanding of the relationship between breathing and swallowing; to find simple, non invasive methods of assessing this relationship; and to develop predictive indices for clinicians to use at the bedside.

1.01 Respiratory control and swallowing:

Humans do not normally breathe and swallow at the same time. A healthy adult can consciously arrest respiration at any phase in order to swallow (Martin, 1994). Swallowing normally follows a well-defined pattern: the pharyngeal stage of swallowing is almost always followed by a large expiration (Nishino, 1985). It is thought that the reason for this is to reduce the risk of 'mist aspiration' (air held in the pharynx, saturated with food or fluid particles which are then inspired) (Shelley, 1989). There are other changes to the respiratory cycle during swallowing. These are not random changes, but rather a rearrangement of respiration into a well-controlled pattern initiated by a variety of sensory inputs. The most important of these is a stimulus to the swallow centre via the sensory side of the reflex arc, thereby triggering the pharyngeal stage of the swallow.

Swallowing and respiration are normally co-ordinated so that a swallow causes minimal or no disturbance to continuing respiration. Various studies of healthy volunteers have shown that when a swallow occurs late in expiration, the expiration is prolonged thereby guarding against inadvertent aspiration (Selley 1989, Nishino 1985). However, if the swallow occurs early in expiration, this prolongation is less marked. Furthermore, this pattern was found to be maintained whether a swallow was spontaneous or triggered by drinking water.

However, these observations differed in another study (Smith, 1989) where it was found that a general irregularity in breathing occurred during drinking. The most likely reason for this difference is that Smith used an alternative method of

assessing breathing patterns (plethysmography and electromyelography (EMG)) from the other studies as well as different sampling and analysis.

Selley (1989) and Nishino (1985) also found that a swallow which coincided with the inspiratory phase was found to interrupt inspiration immediately. It was then always followed by a short expiratory phase. They both identified two other positive correlations; the first between the time of the onset of expiration to the onset of the swallow and the other with the duration of the expiration interrupted by swallowing. This indicates that the later the onset of a swallow, the more expiration is prolonged.

In these studies the duration of the respiratory cycle in the breaths immediately following a swallow, was not affected by the swallow but there was considerable increase in the tidal volume of the post swallowing breaths. These results suggest that the changes in respiratory pattern induced by the act of swallowing may depend on some mechanism (probably the swallowing centres in the brain) that actively regulates the co ordination of respiration and swallowing allowing a proportional increase or decrease in the swallow apnoea period in normal healthy subjects.

If the premise that basic involuntary respiratory control during swallowing is through the swallow centres of the brain is accepted; then any damage to these centres, through for example neurological pathology, would disrupt the essential co-ordination. Some neurological conditions are associated with abnormal respiratory patterns during and following swallowing. Selley et al (1989) and Martin (1994) conducted studies with patients who had sustained a cerebral vascular accident (CVA) or stroke. Stroke is one of the main causes of death and disability in the U.K., affecting about 100,000 people per year. In both studies subjects' respiratory patterns were studied before, during and after swallowing and showed considerable variability. Most of the dysphagic stroke patients in these studies inhaled immediately after swallowing, thereby increasing their risk

of mist aspiration. This suggests that stroke may disrupt the healthy swallow - breathe relationship in some subjects. Further studies on patients with stroke by Gordon also found that most subjects exhibited a characteristic abnormal respiratory pattern consisting of a slight prolongation of deglutition apnoea (breath held during the pharyngeal stage of the swallow), (Gordon, 1987). Selley et al (1989) also found that by studying people's breathing patterns during swallowing they were able to identify patients who were at risk of aspiration who had neurological pathologies other than stroke.

These studies would appear to support the theory that there is a control link between the respiratory and swallow centres in the brain. Anything affecting the neurological centres controlling this process may show itself in changes to breathing patterns and subsequent aspiration. However, there are many other reasons why people may have changes in breathing patterns and respiratory function following impairments such as stroke. These will be explored later in this chapter.

1.02 Respiratory Impairment:

Breathing patterns in stroke:

There are a number of proposed mechanisms that may account for changes in breathing patterns frequently seen in stroke patients. Possibly the most significant are damage to the respiratory centres, and reduced thoracic excursion. The latter may be due to muscle weakness or paralysis, in-coordination of breathing patterns, or a combination of these two.

Damage to the respiratory centres can be direct or indirect. Cerebral breakdown products may indirectly stimulate the respiratory centres of the brain or the brainstem and respiratory centres may be directly damaged by the stroke. Vingerhoets (1994) described a number of lesion sites within the brain which may

lead to respiratory abnormality following stroke. This destruction or disruption of the respiratory centres in the brainstem can result in classical patterns of respiratory dysfunction such as Ondine's Curse and Cheyne Stokes.

Stroke is a condition that predominately affects older people which means that this patient group is likely to have co-morbidities such as chronic obstructive pulmonary disease. The presence of lung disease may exacerbate obvious respiratory patterns following stroke. Reduced chest wall mobility can also be caused by conditions such as kyphoscoliosis or obesity.

Vingerhoets (1994) also suggested that the pattern of a patient's breathing in the early phase after a stroke could serve as a prognostic indicator of survival. This concurs with earlier work done by Severinghaus (1962). In this later study 40% of patients presenting with tachypnoea following a stroke died in contrast to only 18% with a normal respiratory pattern. The study found no relationship between the location of the area of infarction causing the stroke and the presence of tachypnoea. The majority of the stroke patients presenting with tachypnoea had a concurrent metabolic acidosis or lung abnormality supporting the theory that previous lung function may have a role in changes in breathing patterns post stroke. However Simon (1990) and Yamour (1980) have both proposed a different mechanism. They hypothesised that primary central nervous system lesions might lead directly to cardiac and pulmonary dysfunction and that dysfunctional breathing patterns did not relate to lung function prior to the stroke. Therefore the relevance of pre existing lung disorders to abnormal breathing patterns post stroke is still unknown.

Reduced chest wall movement and reduced diaphragmatic excursion have been reported following a stroke. Fluck (1966) was one of the first researchers to note that involuntary chest movements become altered following a stroke and that there was a reduction in the range of movement within the thorax. He found that the affected side moves 9.2% less than the unaffected side during tidal and that

during deeper breathing the difference increased to 16.9%. DeTroyer et al (1980) similarly documented reduced lung excursion in a study of 20 stroke patients

Gas exchange:

Some patients have been found to have altered oxygen saturation levels post stroke. This may be related to the patients' posture. Sulter et al (2000) studied 49 stroke patients following acute strokes for the first 48 hours post admission by using oximetry and found 63% of patients had desaturations below 96% lasting longer than 5 minutes. A controlled study by Roffe et al (2003) studying 100 acute stroke patients for 72 hours, defining desaturations as a 4% fall from baseline concurred with this finding. Acute stroke patients were more likely to experience prolonged periods of desaturation and have lower levels of oxygen saturation than control subjects at rest before attempting to swallow. These studies show that a large number of stroke patients demonstrate a degree of hypoxia. The authors argue that these respiratory changes result from varying causes including central brain damage, reduced lung movement and breathing in-coordination. The subject's ability to swallow was not considered. Clague (1976) studied eight patients with hemiplegia who were asked to sit or lie in different positions and found that arterial oxygen tension was reduced (to 81% of predicted) when sitting but fell by further 19% in right sided weakness and 10% in left sided weakness. When the patients were placed in the supine position seven out of the eight subjects demonstrated significant airway closure. However, this was a small, uncontrolled study, making generalisation more difficult.

The effect of position was also studied by Walshaw (1984) who compared stroke patients with early dense hemiplegia compared with 16 matched controls and found that patients with acute hemiplegia tended to lie with the non - paralysed side uppermost. It was surmised that this would increase blood flow to the dependant and hypoventilated lung, thereby increasing pulmonary shunting and resulting hypoxia. His observations suggest that early stroke patients become

hypoxic, primarily due to muscle failure in the chest rather than a central respiratory dysfunction. This hypothesis is supported by the findings of Elizabeth et al (1993) who compared 10 elderly patients with stroke with 10 aged matched controls (who were in the hospital with other illnesses) recording oxygen saturation levels less than 90% dependant on nursing position. It was found that the best position to maintain oxygen saturation in stroke subjects was "propped". Chatterton et al (2000) study however disagreed with this finding. They observed oxygen saturation levels in stroke patients during 4 resting positions and found no significant differences. Leading them to conclude that hypoxia relates to central respiratory dysfunction rather than muscle weakness exacerbated by position. However, Chatterton et al. only studied patients for 1 hour in each position whereas Elizabeth's team recorded saturation levels in-patients for 48 hours.

As previously stated, swallowing and breathing are intrinsically linked, so it is possible that the patients breathing pattern serves as an indicator of a swallowing problem. In summary, there are a number of proposed mechanisms that may account for changes in breathing patterns seen in patients who have had a stroke. These include neurologically induced muscle weakness and in-coordination, patient posture and direct respiratory centre dysfunction. Evidence from other neurological conditions, such as motor neurone disease and multiple sclerosis would suggest that alterations to the cough reflex, and subsequent aspiration are also an important element in the aetiology of disordered respiration.

Breathing patterns in progressive neuromuscular diseases:

In healthy people ventilation reduces during sleep. Respiratory muscle weakness, bulbar failure or disturbance of the automatic control of respiration exacerbates this normal nocturnal hypoventilation and may precipitate respiratory insufficiency i.e. hypercapnia and hypoxia (Laroche 1989) in progressive

muscular diseases. This occurs most commonly as a consequence of neuromuscular weakness but may also be due to, or accompany disturbances of the brainstem or an interruption of descending respiratory pathways. Initially any symptoms may be primarily nocturnal because during Rapid Eye Movement (REM) sleep, the body relies exclusively on the diaphragm to breathe. If this is impaired through weakness or paralysis the other respiratory muscles are not able to compensate, leading to desaturation and consequential tissue hypoxia occurs. 'Although the effects of respiratory failure due to neuromuscular disease can become obvious, the initial abnormality is disordered breathing during sleep' (Phillipson & Bowes 1986). However as the disease progresses patients may find they develop breathing difficulties in the day as well as at night.

Inspiratory and expiratory muscle weakness do not necessarily develop at the same time and each may have different consequences. Expiratory muscle weakness may lead to an impaired ability to cough; this may be linked to aspiration and or bronchopneumonia, particularly if there is an associated bulbar weakness. The consequences of inspiratory muscle weakness include widespread atelectasis, reduced compliance, ventilatory perfusion inequality and impaired airway patency. The muscles in someone with neurological disease are inevitably working closer to their fatigue threshold than in a healthy person (Moxham 1990). Once a critical level of reduced pulmonary function has been reached then any additional respiratory load such as infection may precipitate fatigue and respiratory failure. Weakness of the abdominal muscles also reduces the capacity to cough and this may also be combined with other factors such as medication which may precipitate a reduced respiratory reserve, desaturation and possible hypoxia.

Ventilatory failure is the most common cause of death in motor neurone disease. In motor neurone disease there a degeneration of motor nuclei of the brain stem, leading to paralysis of the respiratory muscles resulting in hypoventilation and reduced ability to cough and possibly decreased sensitivity to carbon dioxide

within the respiratory centres. Lyall (2001) found in a study of patients with motor neurone disease they suffered from mainly central apnoea due to respiratory muscle weakness. However Gay (1991) found that 50% of patients with motor neurone disease had obstructive apnoea with the remaining 50% having central or mixed apnoea. The probable reason for the differences in findings is the techniques used to measure apnoeas. Periodic apnoea is conventionally divided into obstructive and central types. In obstructive apnoea there is upper airway obstruction despite normal movements of the intercostal muscles and diaphragm. In central apnoea all phased respiratory movements are absent (Douglas 1984). Howard (1989) demonstrated that in conditions such as motor neurone disease the diaphragm might be preferentially affected which would cause a disordered breathing pattern especially when sleeping and in REM sleep but would also have an impact on breathing when awake . Hypoventilation and apnoeic periods during sleep or a variable pattern of tidal volume or frequency suggest impaired automatic control of ventilation (Howard 1991). If the patient is unable to cough effectively, secretions, aspirated food or fluid may cause upper airway obstruction either completely or partially. This may lead to oxygen desaturation and consequent tissue hypoxia.

Similar patterns of respiratory involvement are seen in other neurological conditions such as multiple sclerosis. Oxygen desaturation may be due to: respiratory failure due to demyelinating lesions of the cervical spinal cord or of the respiratory centres in the medulla. This may lead to apnoea or altered ventilatory patterns. Hemidiaphragmatic paralysis and bilateral diaphragm weakness may occur due to the involvement of the cervical spinal cord. The patients may also develop bulbar weakness, reducing the ability to cough leading to the problems described above.

1.03 Methods of assessing respiratory impairment:

This section reviews the techniques for assessing respiratory function. Means of assessing respiratory function in a standardised way are desirable for both the clinician and the researcher. Accurate assessment aims to provide a baseline measure of a person's function and a means of assessing improvement or deterioration. The main areas of interest to clinicians working with respiratory disease are respiratory muscle function, lung volume, airway calibre and oxygen/ carbon dioxide levels. Equipment which is commonly used to measure respiratory function at the bedside includes pulse oximetry, spirometry and muscle strength measurements by mouth pressure meters.

a) Pulse oximeter

Pulse oximetry (see figure 1.01) is a simple non-invasive method of monitoring the percentage of haemoglobin (Hb) that is saturated with oxygen. A pulse oximeter consists of a probe attached to a patient's earlobe or finger which is linked to a computerised unit. The unit displays the percentage of Hb saturated with oxygen and may give an audible signal for the pulse. A pulse oximeter works on the principle that deoxygenated and oxygenated haemoglobin exhibit different absorption characteristics to red and infrared light. The two wavelengths of light (650 nm and 805 nm) are emitted from the probe. Reduced haemoglobin absorbs greater amounts of infrared light, while oxygenated haemoglobin absorbs greater amounts of red light. By calculating the absorption at the two wave lengths the processor can compute the proportion of haemoglobin which is oxygenated. This provides an indirect measure of oxygen content. The accuracy of the arterial oxygen saturation levels measured by pulse oximetry compared with those measured directly by blood gas analysis is widely accepted as +/- 2 %. It is considered to be less accurate when the level of oxygenation is below 70% saturation.

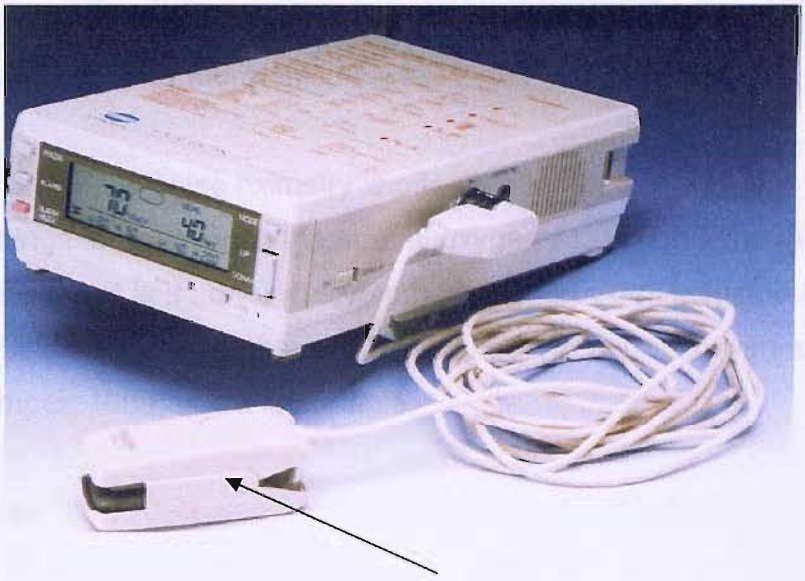


Figure 1.01 Pulse oximeter – arrow illustrating finger probe

Pulse oximetry cannot be considered reliable if the patient has peripheral vasoconstriction, hypovolaemia, severe hypotension, cold, cardiac failure, certain cardiac arrhythmias or peripheral vascular disease. These conditions can all cause a reduction in peripheral pulsatile blood flow which produces an inadequate signal for analysis. If the oximeter is used when there are bright overhead lights this may contaminate the infrared signal leading to inaccurate computations of oxygenation. The accuracy will also be affected by something called movement artefact, this is caused by movement of the probe e.g. shivering and may cause difficulties in picking up an adequate signal. If the patient is wearing nail varnish then this may cause falsely low readings. The results however are not affected by jaundice, dark skin or anaemia. Pulse oximeters cannot distinguish between different forms of haemoglobin. Carboxyhaemoglobin (found in smokers) is registered as 90% oxygenated haemoglobin and 10% desaturated haemoglobin, this leads to an overestimation of overall oxygen saturation. Finally venous congestion, particularly caused by tricuspid regurgitation may produce falsely low readings. Where the flow is sluggish e.g. hypovolaemia, or vasoconstriction, then the oximeter may be unable to function.

This is because the computer within the oximeter is incapable of distinguishing pulsatile flow from other more static signals.

Despite its limitations pulse oximetry is often the method of choice in many hospital settings for measuring the arterial oxygen saturation for some of the following reasons: it is a non- invasive procedure, provides continuous monitoring, is simple to use, the results are known to correlate with arterial blood gases (Tremper, 1989) and it is portable.

b) Spirometer

The objective of spirometry is to assess ventilatory function, by measuring lung volume and airway calibre. Spirometry measures changes in lung volume by recording changes in the volume of air exchanged through the airway opening. The vital capacity (VC) is the volume of air a subject is able to expire after a maximal inspiration to the total lung capacity. Spirometry is limited to vital capacity and its subdivisions because the residual volume in a person's lungs cannot be exhaled. A forced vital capacity (FVC (l)) means that a maximal expiratory effort was made during this manoeuvre. Forced expiratory volume in one second (FEV_1) can also be obtained. This is the volume of air (l) expelled in the first second of a maximal forced expiration from a position of full inspiration. Forced expiratory ratio (FEV_1%) is the FEV_1 expressed as a percentage of the FVC or VC i.e. the proportion of the vital capacity exhaled in the first second. It allows a distinction to be made between a reduced FEV_1 due to restrictive lung volume and that due to obstruction. The ratio is independent of the FVC but has the disadvantage that in the presence of airflow limitation the denominator is reduced by dynamic compression. The MEF_{25-75} is the maximal mid expiratory flow measured over the middle half of forced expiration and is measured in litres per second (ls). In the presence of a normal FEV_1 a reduced MEF_{25-75} is evidence for mild airflow limitation. Peak expiratory flow (PEF) is the maximum rate of airflow which can be produced during a sudden forced expiration and is

measured in litres per second exhaled (ls). Peak expiratory flow reflects mainly the calibre of the bronchi and is used for assessing bronchodilatation.

Some spirometers can be handheld, see figure 1.02. Patients are required to blow as long and as hard as possible into a mouthpiece. A disposable mouthpiece is used for each patient. Spirometry is the method of choice in many hospitals for a basic respiratory assessment because, it is a non invasive procedure, is simple to use, portable devices are available cheaply, its results are easy to interpret and there are well established normative data.

However it does have some limitations as it is dependant on patients being able to follow instructions and physically perform the manoeuvres required. It is considered to be an effort dependant test that is the subject's initial degree of effort may affect the consistency of the result. Once the expiration has started it then becomes effort independent and FEV_1 is dependent on lung mechanism, not effort.

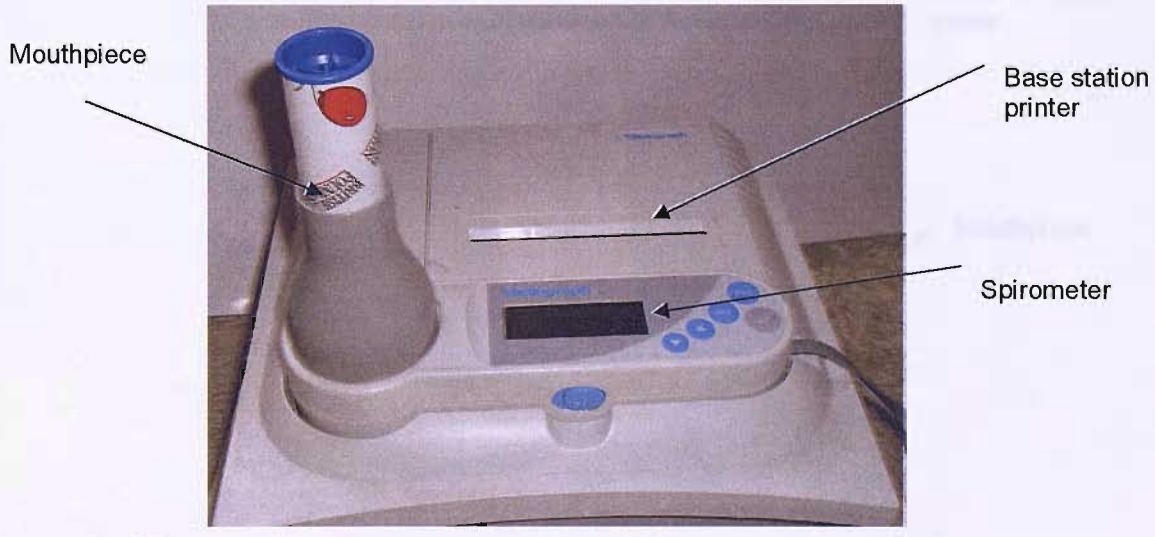


Figure 1.02: portable spirometry system with base station printer

c) Mouth Pressure Meter (Precision Medical Ltd, UK)

The assessment of respiratory muscle force generation is indirect and can be voluntary or involuntary. Measurement of transdiaphragmatic pressures (which require the use of oesophageal balloon catheters) isolates the diaphragm and are of limited use in a clinical setting. Maximal inspiratory and expiratory pressures can be measured at the mouth (MIP & MEP) but involve all the respiratory muscles. A mouth pressure meter, (see figure 1.03) can be used clinically as an indirect index of respiratory muscle strength. Normal values for these tests are available from the work of Leech (1983), Vinken (1987) and Wilson (1984). In common with many lung function measurements these tests are effort dependent and there is wide inter subject variability. The mouth piece is similar to that used by scuba divers and some subjects who have a severe respiratory compromise may find this difficult to use. Measures of mouth pressures have also been shown to exhibit intra and inter operator variability (Multz 1990), although this may be offset by a learned response (Larson 1993).

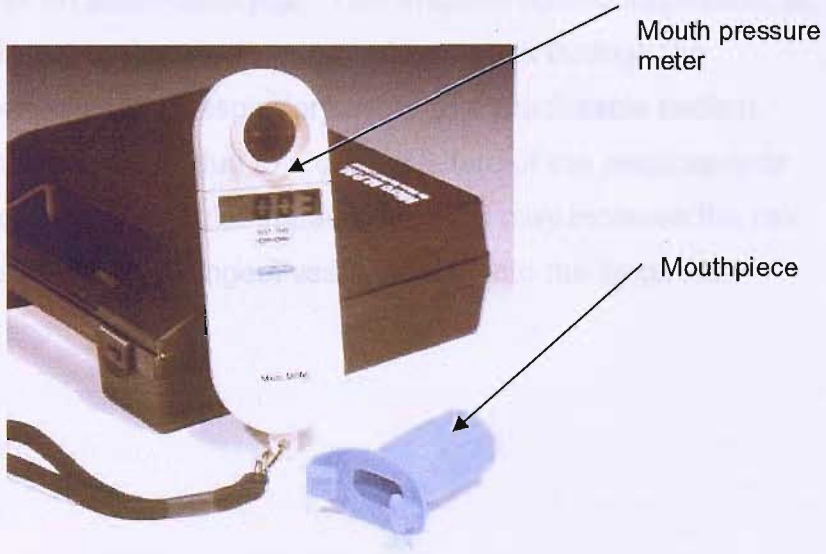


Figure 1.03: mouth pressure meter

These simple investigations can help elucidate respiratory function at the bedside. If used within the confines laid out within the text, pulse oximetry is an accurate estimator of real time arterial oxygen concentration. Spirometry is an accurate, non invasive method for assessing basic respiratory function but it requires co-operation and co-ordination to perform it correctly. Mouth pressure meters can be used as a measure of respiratory muscle strength but also require a degree of comprehension, co-operation and co-ordination.

1.04 Swallowing Impairments:

The pharynx is the shared pathway for both breathing and swallowing. Swallowing is divided into voluntary and automatic stages. A person can continue to breathe while chewing food or holding drink within the mouth. This is called the voluntary stage of swallowing. Once the bolus is propelled between the pillars of fauces, the swallowing and respiratory centres are triggered and the swallow becomes part of an automatic cycle. This involves halting inspiration, at a set point of the respiratory cycle, allowing the bolus to pass through the pharynx cleanly and then restarting respiratory cycle, in a predictable pattern. Any disruption to this pattern, either due to a central failure of the respiratory or swallowing centres or due to a muscular impairment, then may increase the risk of aspirating food or fluid into the laryngeal vestibule and into the lungs (see figure 1.04).

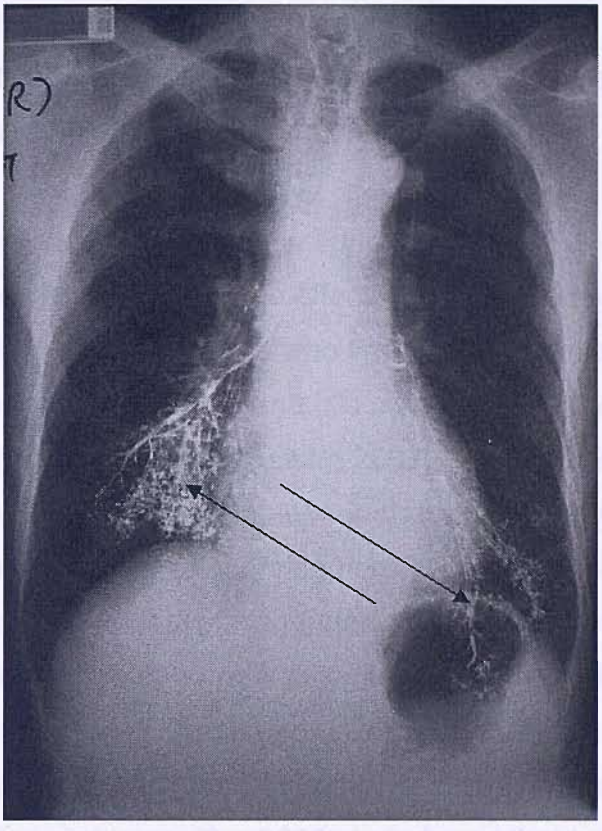


Figure 1.04: AP view x-ray of thorax demonstrating aspiration – arrows point to barium aspirated into the bronchial tree

The following section reviews the incidence of dysphagia (swallowing impairments) and silent aspiration (food or fluid entering into the lung with no obvious signs of distress) in patients with neurological disease and the possible mechanisms of oxygen desaturation which is frequently observed in these patients. This is followed by a review of the methods currently used for the assessment of dysphagia and examines the value of oximetry in detecting silent aspiration. Finally, the hypothesis and aims of the first study are stated.

Dysphagia is common in patients with neurological disease. The detection of this complication is important as silent aspiration in dysphagic patients may lead to hypoxia, chest infection and sepsis (Barer 1989). However, the methods currently used for the assessment of dysphagia either lack the sensitivity to detect silent aspiration or are not practical in acutely ill patients e.g. videofluoroscopy (a radiological screening technique).

Swallowing patterns in snoring and sleep apnoea:

There have been detailed reports of the effects of snoring on sleep and its possible relationship to stroke. People who snore tend to have a larger neck circumference than those that do not and it is a well known risk factor in sleep apnoea syndrome (Davis 1990, 1992, Listro 2003). During waking, however, snorers (even if they do not have sleep apnoea) are more likely to have collapsible upper airways than non snoring normals (Issa 1984). The mechanism for this is unclear but Series et al (1995) found differences in the muscle fibres of the uvula between snorers and normal subjects. Others have suggested fatty deposits within the muscles of the pharynx (Hoffstein 1996). It has been postulated by Jaghagen et al (2000, 2003) that people who snore have subclinical swallowing problems. The 2000 study found that habitual snorers had neurological lesions within the palatal tissues which Jaghagen suggested may be linked to reduced pharyngeal sensitivity. The team tested this by looking at 41 snorers and 15 non snoring controls swallowing using videofluoroscopy. They found swallowing dysfunction in 54% of the snoring population and 7% of the controls. A similar study was carried out in 2003 looking for differences in swallowing comparing normal subjects to those with differing degrees of sleep apnoea. The team assessed 66 snorers and 15 non snoring controls swallowing using videofluoroscopy. They found swallowing dysfunction in 52% of the snoring population and 7% of the controls. If snoring does cause damage to the pharynx and reduces the sensitivity of the swallow then it is possible that people who have a neurological disorder and who snore are at more risk of a swallowing problem than those who do not, simply because the underlying structures that

influence swallowing are already disordered. To date no studies have been published looking at the relationship between snoring and neurological dysphagia.

Swallowing patterns and smoking

Langmore et al (1998) carried out a prospective outcomes study of 189 elderly subjects, who were followed up for 4 years. She studied a number of possible predictors of aspiration pneumonia and found that one of the best predictors for a person developing aspiration pneumonia was impaired swallowing, with an odds ratio of 19.98. She postulated that this was due to the fact that smokers and people who have associated chronic obstructive pulmonary disease have an impaired ability to clear their lungs thereby allowing the presence of opportunistic bacteria to flourish in the lungs. Nilsson et al also recorded smoking behaviour in their study of 33 patients attending videofluoroscopy clinic, trying to quantify swallowing behaviours (1998). Their study numbers were too small to discover whether smoking affected outcome but they did suggest that swallowing ability was affected by a respiratory drive disorder. Dua et al (2002) found that smoking increased the delay in triggering a pharyngeal swallow in otherwise healthy subjects. They also found in their study of 10 smokers and 10 non smokers using nasendoscopy that smokers needed a larger bolus than non smokers to trigger the swallow. If smoking reduces the sensitivity within the pharynx for swallowing then it is possible that this could influence the ability of people with a neurological disorder to swallow.

Swallowing patterns in stroke:

As well as altering breathing patterns, dysphagia is common following a stroke, particularly hemisphere and brain stem stroke. The reported incidence of dysphagia after stroke ranges from 25% (Linden, 1983) to 50% (Mann, 2000). Like respiratory impairment dysphagia may be caused by direct central damage

(and or the subsequent breakdown of brain products after the initial insult) to the swallowing and respiratory centres in the brain. Alternatively it might be due to bulbar weakness causing difficulties controlling the bolus of food and drink through the oropharyngeal tract. The incidence of dysphagia post stroke seems to be increasing, as measured by referral rates to speech and language therapists (Enderby and Petheram 2002) but no papers have questioned why this is occurring. The greater availability of videofluoroscopy and other objective investigations that measure dysphagia may be increasing the rate of diagnosis. Or there may be a genuine change in the stroke population, as a result of our ability to enable patients with more severe strokes to survive.

Aspiration is common in the first four weeks following stroke and women are more likely to suffer dysphagia than men (Roquer et al 2003). It is believed that even a single episode of aspiration can lead to pneumonia, sepsis, dehydration and malnutrition (Barer, 1989, Celifarca, 1990, Horner, 1988). Dysphagia can occur following brainstem, bilateral and unilateral strokes. Among those stroke patients with dysphagia in the first three weeks post onset it is estimated that one third of all patients will aspirate (Logemann 1983). The primary features of dysphagia in this acute stroke population are inco-ordination of the oral phase and delayed triggering of the swallow reflex (Veiss, 1985).

Swallowing patterns in head injury:

The incidence of head injury, leading to hospital admission, is approximately 300 per 100,000. Brain damage occurs both at impact and as a result of the development of secondary complications. Trauma to the brain, brain stem or cranial nerves may lead to dysphagia (Brown 1992, Dworkin 1991, Lazerus 1989). The incidence and specific nature of swallowing disorders as a result of traumatic brain injury has not been extensively studied. One study suggested that there was a 27% incidence of dysphagia in patients with traumatic brain injury admitted to a rehabilitation setting (likely to represent 2-5% of those injured) during a one year period of time. However the paper is not clear as to

the length of time post initial insult or the range of patients admitted (Cherney 1996).

Swallowing patterns in progressive neurological diseases:
Many acquired neurological diseases may demonstrate dysphagia as a symptom. Motor neurone disease (MND) has an incidence of 2 per 100,000. There are 3 main subtypes of MND each with a differing pattern of upper and lower motor neurone degeneration. It is a disease of middle age and older people. People with the bulbar form of motor neurone disease may experience dysphagia as an early presenting symptom due to atrophy of the tongue and pharyngeal musculature. The likelihood of aspiration and malnutrition is very high and increases as the disease progresses (Wilson 1990).

Parkinson's disease (PD) has an incidence of 20 per 100,000. In most cases the age of onset is from 50 years upwards with incidence peaking in the mid 70s. People who have Parkinson's disease are prone to oral, pharyngeal and oesophageal dysfunction. Bradykinesia of the tongue may interfere with secretion and bolus control with reduced tongue driving force. This in turn leads to reduced clearance of the bolus from the pharynx. Patients may often experience disturbed oesophageal contractions resulting in slowed transit and discomfort and dismotility and possibly reflux (Stroudley 1991, Croxon 1988, Neumann 1995, Kuhlemeier 1994). Swallowing problems in patients with Parkinson's disease are frequently underestimated by patients and clinicians (Willig 1994). Some subtypes of Parkinson's disease are known to have central respiratory problems and this also impacts on the patients ability to co-ordinate their breathing and swallowing.

Huntington's disease is an autosomal dominant disorder with onset normally in middle life. Dysphagia is a common symptom which when combined with respiratory complications is often indicative of the terminal stage of the disease (Hunt 1989, Leopold 1985). The oral stage of the swallow is most commonly

affected due to impaired control which is usually associated with the presence of choreic movements of the tongue and lips (Kagel 1992).

Multiple Sclerosis is a disease that usually presents in young adults with a peak age incidence of 20 –40 years. Females are more likely to be affected than males in a ration of 3:2. The prevalence differs at various latitudes, being highest in temperate climates. Dysphagia in multiple sclerosis occurs when the corticobulbar or connections to the lower brainstem nuclei become affected by the demyelination process (Boucher 1991). One study has indicated that although abnormal swallowing is common, patients frequently do not complain of any symptoms (Thomas 1999). Those that do, complain of disturbed sensations of taste and smell, "sticking in the throat" and variable performance in the ability to swallow. Dysphagia in multiple sclerosis is also characterised by reduced muscle strength with abnormal tone to the oral stage musculature (Catalanotto 1994, Hartelius 1994).

In summary the incidence of dysphagia and silent aspiration in people with neurological disease is high. The different features of neurogenic dysphagia are summarised in Table 1.01. There may be a link between sleep apnoea, snoring and dysphagia but there is insufficient evidence at present to confirm this and it is yet to be proven in a robust clinical trial.

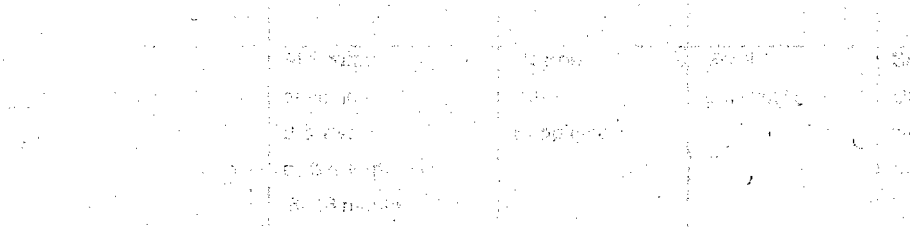


Table 1.01: Summary table of features of neurogenic dysphagia

	Age of onset	Natural course of dysphagia	Onset of dysphagia	Awareness of dysphagia	Presenting features of dysphagia
Acute Stroke <4 weeks	Can be any age but more common with older persons	Death in 1/3rd, full recovery in 1/3rd and continuing disability 1/3rd	At least 33% of pts present with dysphagia. Likely to start immediately	Variable but often no awareness	Usually unilateral damage - may be bilateral with brainstem injury
Sub-acute Stroke >4 weeks	Can be any age but more common with older persons	Increased risk of further strokes. Most recovery in first year, slowing thereafter	25-50% of presenting dysphagic pts have persisting dysphagia	Variable but often no awareness	May be oral or pharyngeal stage disorder, often silent aspiration and ↓ sensation & awareness
Head Injury	Can be any age but most common in young men and older persons	If survive initial trauma is pattern of initial measurable improvement in first year followed by slowed but continued progress	Immediate – may be due to facial injury or neurological damage in 27%	Variable but often no awareness	Often unaware or distractible, initiation difficulties and reduced tongue movement ↓ secretion & bolus control
Parkinson's Disease	Onset usually in 60's or 70's	Slowly progressive	Usually appears later in disease	May be unaware; pt reports are unreliable	Oral, pharyngeal and oesophageal dysfunction, rigidity of tongue, ↓ secretion & bolus control
Huntington's Disease	Onset in midlife	Death typically occurs 15-20 yrs post onset	Varies considerably	Dysphagia not universal; pts subjective reports are not reliable	Oral stage disorder with choreic tongue and lip mvmts – limited respiratory co-ordination
Multiple Sclerosis	Onset in young to middle age adults	Highly variable most common pattern is remission and relapse	Not universal depends on site of lesion	Variable awareness	Reduced muscle strength and abnormal tone of oral musculature
Motor Neurone Disease	Mean age of onset for ALS 55 , bulbar form 70	ALS form death in 5-8 yrs, bulbar form 6- 18 months	May be initial symptoms	Good awareness	Subtypes may have UMN or LMN weakness tongue & respiratory involvement

1.05 The relationship of dysphagia to silent aspiration:

As described earlier a proportion of patients who aspirate do so 'silently' (Logemann 1983). Silent aspiration is defined as penetration of saliva or food below the level of the true vocal cords without cough or any outward signs of difficulty (Horner 1990). It is thought that silent aspiration occurs in about 40% of dysphagic patients who aspirate, (Logemann, 1983). There are no reliable clinical indicators of silent aspiration. In overt aspiration patients usually cough, have difficulties or changes in breathing, watering eyes, colour change or have a 'wet' sounding voice. Horner, (1988) found that 90.09% of non aspirating patients (n=21) were more likely to complain of swallowing problems than aspirating subjects (of whom 54% complained of problems) when assessed using videofluoroscopy. The same study also demonstrated that "weak" cough, cough is a sign often associated with the ability to protect the airways, was more likely to occur in silently aspirating patients. However there is no reliable way to assess cough effectiveness at the bedside. The gag reflex, a sign often used to differentiate those who are more or less likely to aspirate, was also found to be diminished in both groups and so can not be considered a reliable predictor of dysphagia. This study suggests that signs which have been used in the clinical setting for a number of years can not be used to predict the patients most likely to aspirate.

Silent aspiration may occur naturally in 'normal healthy' people during sleep or other times of depressed consciousness. Huxley (1978) found in a study of 10 patients with depressed consciousness and 20 healthy controls that 70% (n=7) of patients with depressed consciousness from a variety of pathology, including cerebral vascular disease, aspirated compared with 45% (n=9) of volunteer subjects without impaired consciousness. Pulmonary infections in healthy adults are however uncommon despite this aspiration, but are frequent in patients who have suffered a stroke or who have neurological disease. Huxley suggested that

infection only develops when normal pulmonary defence mechanisms are impaired or overwhelmed which then allows the aspirated bacteria to multiply rapidly.

Silent aspiration occurs in 40% of dysphagic people who aspirate. There are no reliable indicators of silent aspiration. Aspiration may lead to clinically significant events such as pulmonary infections.

1.06 Methods of evaluating dysphagia:

Dysphagia is clearly a common complication of stroke and neurological disease. This makes the detection of aspiration and silent aspiration essential to prevent further medical complications (Kidd, 1995, Johnson 1993, Kalra, 1995) and increased bed occupancy days (Webb, 1995, Bowen, 1994). Identification of the clinical features associated with aspiration in stroke patients may lead to preventative medical and nutritional therapies and a more rapid recovery.

a) The bedside assessment:

Currently the most common method of evaluating patients with dysphagia is the bedside swallowing assessment, (see figure 1.05). However, methods of bedside assessment have not been standardised. Clinical examination usually involves taking an extensive chart and case history review. The clinician will usually evaluate oral motor strength and range of motion, respiratory quality during inspiration and expiration, gag reflex, reflexive and volitional cough, vocal quality and volume, reflexive and volitional swallow, posture, level of alertness and fatigue level.

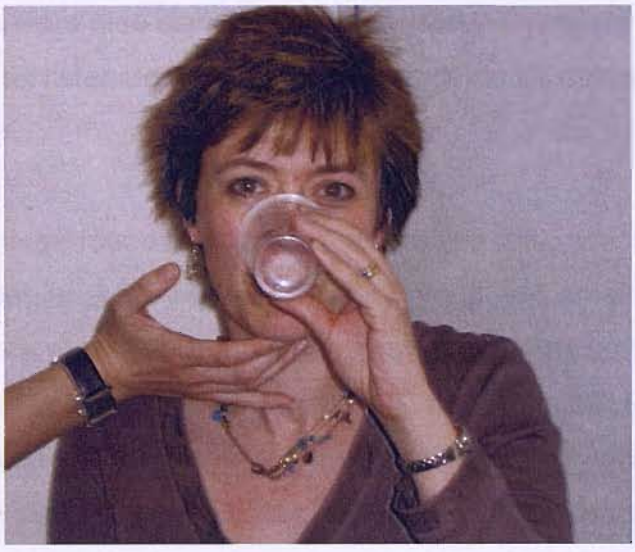


Figure 1.05 : Standard bedside assessment of swallow process. Fingers are placed mid tongue, base of tongue, hyoid and bottom of larynx and a subjective assessment of strength of muscular movement is made.

Swallowing behaviour may be observed using a range of food and fluids with different consistencies. Some therapists however use a water test such as Burke's 3oz water test (De Pippo, 1992) or a standardised meal test such as the Flemming Index (Layne, 1989). The patients' capabilities are then judged by the Speech and Language Therapist evaluating vocal quality, throat clearing, cough, colour changes or signs of respiratory distress, swallow reflex, bolus control and manipulation after each oral introduction of food or fluid. Clinicians then make assumptions based on their observations about pooling of food or fluids in the valleculae or pyriform sinus. Both of the above tests have proved to be unreliable in detecting silent aspiration in the clinical setting unless used in conjunction with other methods (Kidd, 1993). Christina Smith and colleagues (1999) reviewed videofluoroscopies in order to identify whether the ability to cough was valid as an indicator of aspiration and to establish the presence of silent aspiration. They found that from 469 aspirating patients 276 did so silently i.e. without coughing. Men were more likely to aspirate silently, and age and

medical diagnosis were also significantly associated. Therefore studies that rely on methods such as listening for cough at the bedside as markers of aspiration are unreliable.

Younger patients were found to be more likely to aspirate, which concurred with a study by Arvedson et al (1994) but the study group was small. Prudon et al (2005) and Fujimura et al (1996) have both found that females had a more sensitive cough reflex than males when inhaling capsaicin but Roquer et al (2003) when reviewing and quantifying the sex differences in first ever strokes found that women were in fact more likely to be dysphagic than men. Men however were more likely to have thicker necks, snore and have sleep apnoea (Davis 1990).

b) Auscultation:

The bedside assessment of swallowing may be combined with auscultation, which is used to detect swallowing sounds or respiratory sounds, see figure 1.06. The stethoscope may be placed over the lateral border of the trachea, inferior to the cricoid cartilage, or over the centre of the cricoid cartilage or immediately superior to the jugular notch.

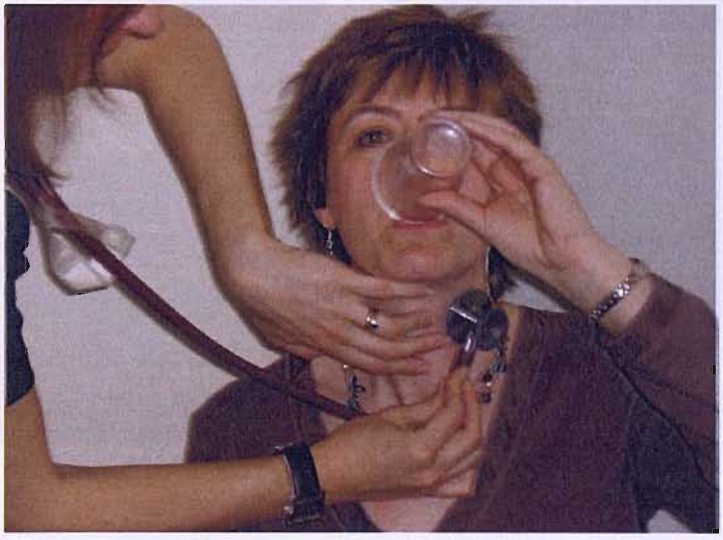


Figure 1.06: Auscultation of throat, bell is placed to listen for swallowing sounds

In a number of studies (Takahashi, 1994, Zenner, 1995 and Hamlet, 1994) auscultation has been shown to be an aid to the bedside assessment by increasing the accuracy in detection of aspiration. Positioning of the stethoscope is a learned technique. Further studies by Stroud (2002) and Leslie (2004) with videofluoroscopy demonstrated this point well and showed that some clinicians are extremely able at using auscultation with enough skill to detect aspiration on its own with all food consistencies. Some clinicians in the studies who had been using auscultation with clients were completely inaccurate (worse than chance) in the detection of aspiration when compared to videofluoroscopy. It is still unclear what the successful clinicians were actually 'listening to' in order to detect aspiration.

c) Manography:

Manography is an invasive procedure, which requires the patient to have pressure probes inserted into the oro-pharyngeal and oesophageal tract, see figure 1.07.

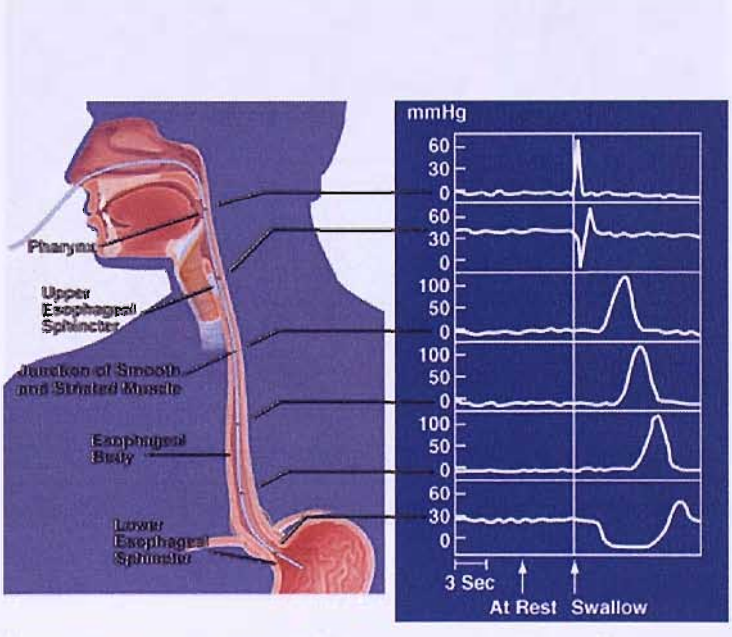


Figure 1.07: Placement of manometry probes for swallowing assessment
(image reproduced with kind permission from Gastro-Pro www.gastro-pro.org)

The patient is asked to swallow a variety of substances and the pressure measurements are recorded as the food passes through the deglutive tract and compared to normative data. This method has the disadvantage of not showing the swallowing mechanism, so using it in isolation; the clinician would be unable to identify the occurrence of aspiration. This technique is not routinely used in the United Kingdom for detection of oropharyngeal dysphagia. It is used for assessment of gastro oesophageal disorders and combined with videofluoroscopy for research purposes.

d) Nasendoscopy:

Fibre optic endoscopy or nasendoscopy is a recently developed method for the assessment of neurological dysphagia. An endoscopic camera is passed through the nose and positioned in the nasopharynx just above the soft palate, (see figure 1.08).

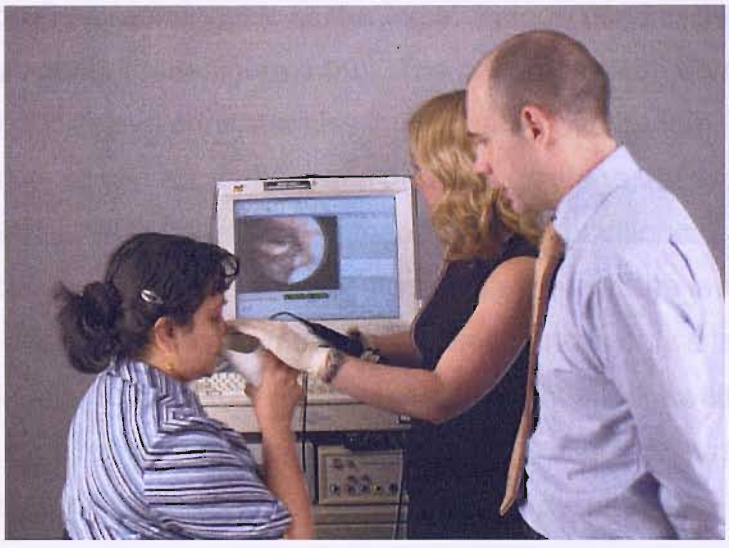


Figure 1.08: Nasendoscope swallowing examination procedure

(Image reproduced with permission from Ms A Kelly)

The patient is then given food and fluid dyed blue and the images are recorded noting pre and post swallowing pooling. In a study by Singh (1995) nasendoscopy was found to be effective in detecting patients who will aspirate in 98% of cases despite the camera being 'whited out' at the point of swallowing. Nasendoscopy does not involve exposure to radiation and could therefore be safely repeated. However it does require a highly skilled technician to pass the instrument and interpret the findings. Some patients poorly tolerate the nasendoscope and in a few extreme cases respiratory arrest has been triggered by the scope touching the epiglottis. Cardiac arrest can also be triggered due to excessive stimulation of the vagus nerve. Other criticisms have been that the swallow mechanism is a closed pressure dependant system. Having a nasendoscope within that system is not only uncomfortable for some people but is likely to alter the mechanism of the swallow.

e) Videofluoroscopy:

Videofluoroscopy is a radiographic screening technique used to detect aspiration in the dysphagic patient (see figure 1.09). The patient is given a variety of food and fluid stuffs of different consistencies impregnated with barium. The procedure permits observation of the oral preparation stage, reflex initiation and pharyngeal transit in both lateral and anterior/posterior positions.
Videofluoroscopy is not suitable for repeated studies due to the levels of radiation. It is costly in terms of time and resources and is only a 'snap shot in time', not taking into account other factors, which might affect swallowing in neurologically impaired patients such as fatigue or positioning. It is however considered the 'gold standard' for the assessment of dysphagia.

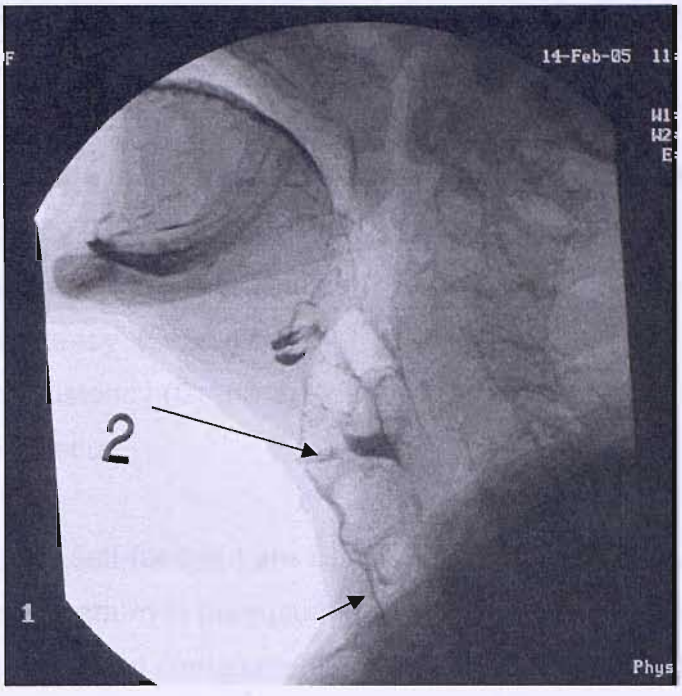


Figure 1.09: Lateral image captured during videofluoroscopy of subject aspirating "grade 2 custard consistency". Short arrow points to aspirated material, longer arrow to the vocal folds

The Radiological Examination Technique used in Videofluoroscopy:
For the evaluation of swallowing, radiology is currently crucial. Radiologically, swallowing can be described in terms of:
1. Displacement of a defined anatomic structure
2. Bolus movement.

Radiological examination takes advantage of the interaction between imaging radiation and material. It is recognised that radiation has a potentially harmful effect and can cause damage. The examination is always performed to keep radiation exposure to a minimum. The patient is placed in an upright position either standing or sitting on the footplate of the X-ray stand, or on a narrow chair.

The fluoroscopy tube is then brought in front of the patient. E-Z-HD barium is mixed in 5 forms:

1. In the standard state recommended by the manufacturers - this is a single cream consistency (Grade 1)
2. In a 1/4 strength consistency – to mimic thin fluid
3. A custard consistency (Grade 2)
4. In a mousse consistency (Grade 3)
5. In a shortbread biscuit.

Patients are asked to self-feed but are assisted if necessary. The patient is asked to keep the ingested barium in the mouth until instructed to swallow. This is intended to reveal failure of containment of the bolus. The entire procedure is videoed automatically which allows for analysis, and the amount of radiation used is printed out and attached to the patients notes. The average amount used in examination is 495 $cGycm^2$.

f) Scintigraphy:

Scintigraphy is a radiographic screening technique. When radionuclides are taken orally (Technetium 99m) and the patient is placed in front of a gamma camera, images of the radiation emitted in the form of a pulse of fluorescent light can be collected, (see figure 1.10). Over time a quantitive picture of the radionuclide transit and metabolism within that organ can be shown as a plot of radioactivity versus time (time activity curve) (Mettler 1991). The technique for swallowing studies has still not been standardised (Espinola 1986, Muz 1987, Holt 1990, Levin 1993 and Silver 1991,1992, 1994, Zoher 1998) and there have been very few rigorous studies of the clinical use versus the current gold standard videofluoroscopy. The potentially most useful element of scintigraphy is the ability to measure the amount of bolus that a patient has aspirated and

possibly more importantly then subsequently cleared, but it does not tell the clinician what is causing the problem in the first place.

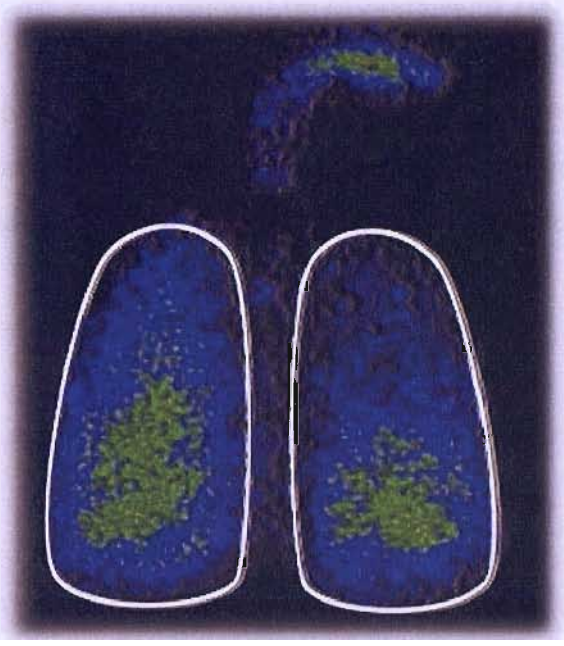


Figure 1.10: Scintigraphy images of lungs used to measure the amount of aspirate inhaled and the deposition pattern. (there are no published examples are of an aspiration event with food but these are the type of images that potentially could be produced)

(reproduced with permission of Honione)

g) The Exeter technique:

Selley (1990) first described this technique. It uses measurements of patients' airflow when eating and drinking. Nasal cannulae are attached to a pressure transducer which records the pattern of nasal airflow (see figure 1.11). Selley and colleagues found that 97% of swallows in normal adults are followed by expiration. This was a ground breaking piece of work in its time but its clinical applications are limited. This is because the method is not sensitive enough to recognise dysphagia in all pathologies and cannot distinguish dysphagia from aspiration. The equipment is also too bulky to be suitable for bedside analysis.

Pinnington, a collaborator of Selley, reviewed the inter-rater and intra-rater reliability of the Exeter technique when applied to healthy elderly adults (2000). She evaluated 3 reviewers of 70 random recordings from 700 on 3 different occasions and found a high rate of inter and intra rater reliability. The Exeter team went on to compare inspiration, expiration and velocity of airflow data with videofluoroscopy (Morton et al 2002). They concluded that aspiration is more common with thin fluids than thick, thereby confirming previous studies.

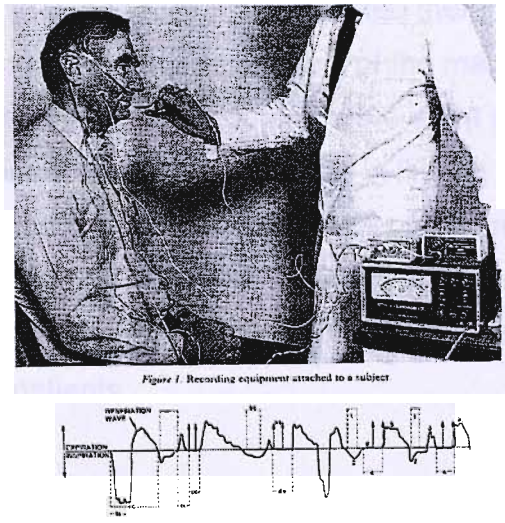


Figure 1.11: Exeter technique for assessment of swallowing the graph below the picture shows the respiratory trace as the subject stops breathing in order to swallow

(reproduced with permission of Dr R E Ellis)

Bish et al (1994) also demonstrated that aspiration is more likely to occur with thin fluids, but that thin fluids stayed longer in the pharynx. They found that when this was combined with disordered respiration there was an increased risk of aspiration. They believe that the quality and control of inspiration and expiration

are likely to be strong indicators for aspiration and that 'high velocity', 'chaotic respiration' was the major cause of aspiration in a variety of people with stroke and neurodisability. 'Chaotic respiration' implies disorganisation of the usual correlation between breathing and swallowing. Individuals will normally breathe out after swallowing but dysphagic subjects usually breathe in after swallowing.

Klahn and Perlman (1999) studied 12 healthy young adults to gain further normative data. They combined sub-mental surface electromyography with what they called a 'respirodeglutometer' (not a standard piece of equipment) to gain qualitative and quantitive information regarding the duration of the apnoeic period during swallowing and the movement of the larynx for different consistencies of food. They found that males and females contracted their larynxes at different times, surmising that this may be due to the bulk of the male larynx being different to the females and therefore requiring more effort and time to move. They agreed with previous work by Selley (1989) in finding that expiration occurred in 93% of the time pre swallow and 100% of the time post swallow. Criticisms may be that the study is very small and is solely based on a healthy population aged 18- 25 years, and is therefore not representative of the population of dysphagic patients.

Hadjikoutis et al (2000) studied 32 patients with motor neurone disease to determine the direction of airflow post swallow. They wished to identify factors associated with an abnormal swallow (i.e. inspiration post swallow apnoea). They used the Exeter technique combined with a "choking diary"; which compared 22 normal subjects with 22 patients with defined neurological disorders other than MND. No subjects had a formal swallowing assessment so dysphagia was not formally confirmed. They found that 44% of the people with motor neurone disease had at least one episode of inspiration post swallow compared to patients with intact swallowing. They propose that it is the presence, not the placement, of lesions that causes inspiration post swallow with certain

neurological conditions and that disordered breathing is an indicator of dysphagia but not aspiration.

Lisa Hirst (Hirst et al 2002) studied several respiratory parameters in 27 "normal" older subjects (mean age 73 years) at rest, during single water swallows and in continuous drinking. They monitored airflow (using the Exeter technique), spirometry pre assessment, limited manometry and continuous oxygen saturation levels via pulse oximetry. They found that 52% subjects had a decrease in saturation levels of 2% or more from baseline. This may have been due to the normal variability stated within the literature regarding pulse oximetry. A further 4 subjects desaturated more than 4% and 10 (41%) subjects inspired immediately post swallow. Hirst et al did not state from where subjects were recruited and their results are unusual if compared with other literature. It is possible that these subjects (may have) had sub-clinical swallowing disorders.

Paula Leslie (Leslie et al 2002) compared the respiration patterns of 11 acute in-patients post stroke, which were suspected of dysphagia following a "bedside" swallow screening assessment with 48 healthy volunteers. They examined length of breathing cycle, respiratory rate and a measure of variability of the breathing cycle, using a modified Exeter technique. She found that five of the eleven stroke patients had significantly disordered breathing, as demonstrated by the Exeter technique, compared with 0 of the 48 controls. She concluded that the presence of dysphagia post stroke is what alters respiratory patterns and not the stroke itself. However she did not study a non dysphagic stroke group: relying instead on previous data from the paper by Lisa Hirst (2002). The patient study group was very small and dysphagia had not been diagnosed by a gold standard method and as previously stated Hirst's paper reported some unusual findings.

In the second paper of the series Leslie (2002) gave 18 suspected dysphagic, stroke patients a videofluoroscopy while observing their respiratory patterns.

She then compared this with 50 control patients who underwent a bedside swallowing assessment, therefore not comparing like with like. She found that the mean apnoeic period of swallowing increased whether the person had sustained a stroke or not. Her observations agreed with previous studies that a healthy population tends to breathe out post swallow rather than in. Leslie et al could not however, as in previous studies, find a specific respiratory pattern which defined aspiration.

h) Electromyography:

Electromyography (EMG) records electrical events which are associated with the first stage of the sequence that links muscle excitation with muscle contraction (Aidley 1989) (see figure 1.12).

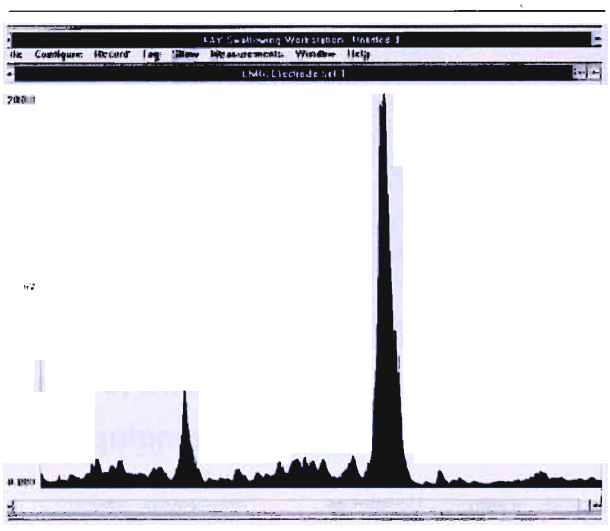


Figure 1.12: EMG tracing of swallow patterns. First spike is a normal swallow, 2nd spike is an effortful swallow demonstrating tongue pressure

The technique may be applied to a specific muscle or nerve which is suspected of pathology or to rate its performance during a specific activity. EMG tracings produce peaks which represent the number of nerve cells firing impulses. A normal swallow will demonstrate a single large peak. EMG has been used to understand and assess swallowing by clinicians (Doty 1956, Palmer 1991, and

Perlman 1989) but their studies have largely focussed on the action of single muscles within a swallow sequence. EMG is also unable to image aspiration.

i) Ultrasound:

Ultrasound is a non-invasive imaging technique, which uses high frequency sound waves (2-10Mhz) to penetrate through the skin and into the soft tissue. It sends these waves into the tissue through the use of a transducer, which then picks up the reflected signal, (see figure 1.13).

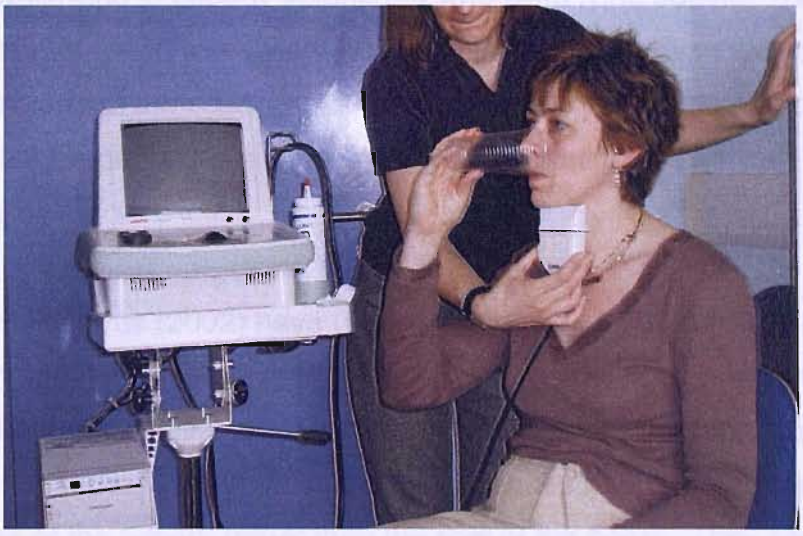


Figure 1.13: Ultrasound of throat image showing placement of ultrasound probe under chin and equipment used

No radiation is used so ultrasound can therefore be used repeatedly, and for extended periods of time. An attempt in the 1980's was made to apply the use of ultrasound to the assessment of swallowing (Shawker et al 1981, 1983,1984). They found that it has many limitations as a technique, primarily because it cannot be used to determine if aspiration has occurred, although one could argue this is merely a limitation of the currently available equipment. The image generated is simply not large enough to view the mouth, pharynx and oesophagus simultaneously. It is further limited by the fact that boney structures such as the hyoid cannot be imaged by ultrasound because it does not pass through bones. Finally, the interpretation is extremely reliant on an

ultrasonographer who would need to be very experienced not only with the anatomy of the oropharyngeal tract but in swallowing interpretation.

j) MRI and CT:

Magnetic resonance imaging (MRI) works by imaging the radio waves produced when a large magnetic field aligns the body's protons for short periods of time. Until recently MRI has only been able to be used in static imaging of the oral and pharyngeal tract. However by using a fast MR imaging technique, Gager (1993) displayed swallowing in healthy volunteers who were lying supine. This is not a normal position in which to swallow food or fluid but the position was constrained by the dimensions of the scanning field. Evans (1994) imaged gastric emptying using modulus blipped echo-planar single pulse technique which can produce an image every 64 ms.

Kitano and colleagues (2002) have used a high speed MRI and turbo flash method to image the swallowing of 12 patients with advanced oral cancer. This is the first study using this technique to look at patients with dysphagia. The authors state that they believe MRI is useful because it focuses on the soft tissue abnormalities of the patient rather than the flow of the bolus. They have defined new parameters which they believe are important to quantify in dysphagia. This is a small study looking at the oral graphs of patients post surgery, not patients with neurological disease and with no discussion about aspiration. The authors admit that more work needs to be done and that the technique will not be available for use at the bedside but this is an exciting new development with evolving technology and could well prove to be of value in the future.

Computed Tomography (CT) uses radiation. An x ray tube is mechanically rotated around the patient, taking density measurements of anatomic structures which are then reconstructed by computer into an axial image of the structure. Swallowing assessment has been limited by the fact that a traditional CT scanner takes too long to image a dynamic image. The patient must also be supine.

Ultra fast and spiral CT scanning techniques are becoming more common as technology evolves. Such methods have obtained images of normal swallowing, (see figures 1.14 & 1.15) (Ergun 1993 and Lin 1994).

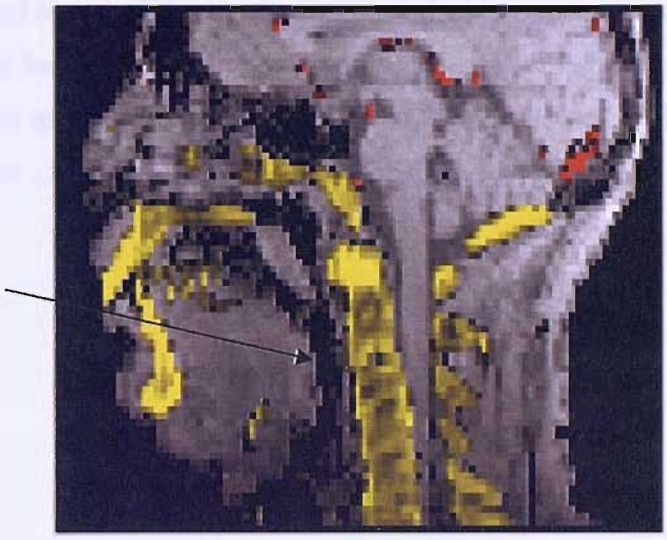


Figure 1.14: C.T./ M.R.I. merge image of neck and swallowing focusing on tongue position as shown by the arrow
(image reproduced with the permission of P Edwards)

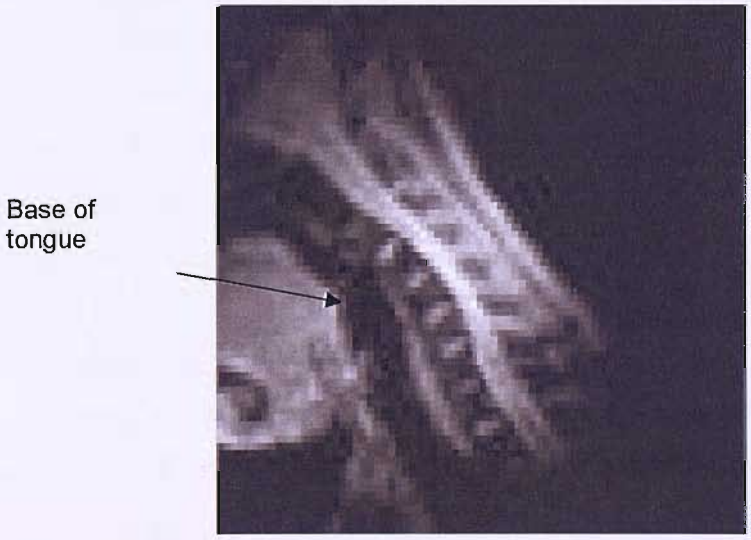


Figure 1.15. Real time MRI image of pharynx *(this is normally a dynamic process and a still has been captured from the examination)*
(reproduced with permission from Fonar The MRI Specialists)

In summary although there are a number of imaging techniques now available the most common form of assessment for dysphagia remains the clinical "bedside" assessment. This is unreliable, has little standardisation and is very dependent on the skills of the clinician. Videofluoroscopy is currently viewed as the gold standard for swallowing assessment, but is expensive and not readily available. Other techniques such as nasendoscopy and scintigraphy are less reliable and yield less information. MRI and CT may be promising techniques for the future but not at the current time.

1.07 Pulse oximetry and aspiration:

The principles of pulse oximetry have been described already in section 1.03, as a method for assessing respiratory function. Pulse oximetry is currently not routinely used in the detection of aspiration but there is some evidence that the technique has potential to be used in this way (Zadi et al 1995, Collins & Bakheit 1997, Smith et al 2000). This section reviews the limited literature on pulse oximetry and aspiration; leading to the hypothesis underpinning the first study. Zaidi et al (1995) studied oxygen desaturation on swallowing in patients with acute stroke. Two control groups were used and consecutive stroke patients admitted into three Manchester hospitals were recruited. Patients were given a maximum of 30 mls of water while oxygen saturation levels were recorded. A Speech and Language Therapist then independently assessed the patients using a bedside assessment and divided them into groups according to their perceived ability to swallow. The study suggested a close relationship between aspiration as determined by the Speech & Language Therapist and the level of oxygen saturation.

Unfortunately this study, as the authors' acknowledged, had several weaknesses. There was no mention of any power calculation in determining the size of the study sample. The control groups were not appropriately matched to the subjects, and as already mentioned the use of the water test is not reliable. Furthermore, assessment of swallowing in these patients was based on the subjective opinion of a Speech and Language Therapist not the gold standard.

Oxygen desaturation has also been documented in adults with other neurological disorders during eating. In a study of only three patients with neurological dysphagia, Rogers (1993) has demonstrated oxygen desaturation using pulse oximetry then as subjects underwent videofluoroscopy assessment to confirm a diagnosis of aspiration. This study is limited by the fact that the studies were not conducted simultaneously and the subject group had significant physical

disabilities which may have lead to variation in the swallowing patterns due to fatigue.

In a similar study Brown (1983) assessed patients with severe chronic obstructive pulmonary disease whilst they were eating meals. Using an ear probe to measure oxygen saturation levels in thirty-three patients with chronic obstructive airways disease, he showed that oxygen saturation levels fell in elderly people with chronic obstructive airways disease when eating, despite the lack of any known neurological deficit in these patients.

This author (Collins & Bakheit 1997) reviewed 54 stroke patients who were suspected of dysphagia and compared videofluoroscopy simultaneously with pulse oximetry in a single blinded study. A fall in oxygen saturation levels of 2% or more was considered to be clinically significant. Results showed that the sensitivity of oximetry was 73% and specificity was 87%; 81.5% of patients were correctly identified by pulse oximetry as either aspirators or non aspirators. The study had weaknesses. The study group was a mixture of acute and sub-acute stroke and not well age matched. A range of 2% is considered within the normal variability of the oximeter so it may be representative of this and not dysphagia. The author feels that this work as it stands is not generalisable to the general dysphagic population.

Cameron Sellars and team (Sellars et al 1998) compared six dysphagic patients with a range of neurological diseases who were attending routine videofluoroscopy with five healthy subjects who had a bedside assessment of swallowing. They found no alterations in the normal subjects' oxygen saturation levels. In the dysphagic group they looked for a drop of more than 4% from baseline measure in oxygen levels. They found 4 out of 6 of the patients had disordered respiration but were hesitant to support oxygen desaturation as a method of detecting aspiration in such a small group of patients.

Bruce Sherman (Sherman 1999) and team studied 46 stroke patients who were clinically suspected of swallowing abnormalities. They compared videofluoroscopy with pulse oximetry, looking for evidence of aspiration and penetration (food or fluid entering into the laryngeal vestibule but not passing below the level of the true cords). They found that patients who aspirated had a significantly greater decline in oxygen levels than those patients who either penetrated and cleared (the ability to move the bolus out of the laryngeal vestibule) or did not penetrate. Patients who penetrated and did not clear had a significantly greater decline in oxygen levels than patients who did not penetrate. They concluded that they found statistically significant differences in oxygen saturation levels between dysphagic and non dysphagic patients; they do however state that further work needs to be done in finding a suitable threshold for the level of desaturation. They also state, because the work has been performed solely with a stroke population, that they do not feel their work is generalisable to the greater dysphagic population and further work needs to be done.

Steven Leder (Leder 2000) reviewed 60 patients in intensive care who had dysphagia of mixed aetiology, using a nasendoscope. He also collected data on blood pressure, heart rate and oxygen saturation. There are some criticisms of this study: patients were assessed with a nasendoscope which potentially alters their swallowing patterns and more than half of the patients also had an nasogastric (NG) feeding tube in the other nostril, also known to alter swallowing patterns. Aspiration cannot be 100% confirmed with this technique as there is no image during a part of the swallow. Leder noted that during the nasendoscope procedure that heart rate and blood pressure were raised and that oxygen saturation levels were variable but not consistent with aspiration. He felt that these changes could have been reproduced by the position of the patient in the bed and he did not support pulse oximetry as a useful tool in the detection of aspiration.

Rowat (2000) compared the oxygen saturation levels of stroke patients who were classified as "safe to feed orally" pre and post meals on a ward with, elderly patients and young healthy controls. She found that 24 % of the stroke patients and 16 % of the elderly patients had a fall of at least 2.5%. The meals were not standardised across the subjects, nor was the method of feeding. None of the patients or controls was objectively assessed for dysphagia but the study states that some of the stroke patients were taking a "modified diet" which this author concludes would imply that there was a degree of problem identified by someone who was concerned with these people's swallowing mechanism. The desaturation may have been caused by occult aspiration but it is impossible to know as no means of objective assessment was used.

Nancy Colodny (2000) analysed 77 "normals" and 104 elderly people diagnosed with dysphagia. She simultaneously assessed patients with nasendoscopy and pulse oximetry. As previously stated nasendoscopy is not the gold standard because the "point of swallow" is "whited out" and that having a nasendoscopy passed potential alters the pressures in the upper airway. She found that dysphagics had lower oxygen saturation levels pre and post feeding but found no correlation between desaturation and aspiration. She did feel however that aspirating patients had compromised respiratory functioning compared with penetrators (people who have food or fluid enter the laryngeal vestibule but it does not pass below the level of the true vocal folds) or normals. In a further paper, which would appear to have used the same study group as the 2000 paper (Colodny 2001), she compared a range of different aetiologies (52% stroke) in 104 dysphagic patients and 77 non dysphagic persons. She reported that oxygen saturation changed dependant on what was aspirated and that patients who aspirated solid boluses were more likely to desaturate than those who aspirated liquid boluses. She took all the recordings and so was not blinded to the findings. She found changes with stroke patients, as did previous studies but not with those who had dementia, a group not studied before with oximetry. She further reported that patients over the age of 80 years had consistently lower

oxygen levels than others, which concurs with other literature for the elderly. She concluded that while patients with dysphagia do not necessarily desaturate when aspirating they may in fact have reduced respiratory function.

Lim and team (Lim 2001) reviewed 50 acute stroke patients comparing bedside assessment, oxygen saturation levels and nasendoscope assessment of swallowing. They used a drop of 2% or more as clinically significant. This means that potentially a percentage of subjects that they assessed as non aspirators may have been aspirating due to the weakness of nasendoscope assessment. They only assessed patients using 50 mls water. They found that pulse oximetry had a sensitivity of 76.9% and a specificity of 83%, almost identical results to this author's previous study with stroke patients.

Higo et al (2003) used a control group and compared it to a group of mixed pathology ENT (including tracheotomy and laryngectomy) and mixed neurology (progressive disease but no CVA) when assessing their swallowing using videofluoroscopy and simultaneous continuous pulse oximetry. They found by using a 2% or more drop in oxygen saturation from a baseline that they could predict aspiration with a sensitivity of 84.6% and specificity of 82.5% in the aspirating neurology group. The authors were reluctant to conclude that the act of aspiration caused the fall in oxygen saturation and felt that breath holding was an important factor. When discussing subjects who 'breath hold' the authors did state that this was done unconsciously by the subject. The authors may have been describing an unrecognised disordered breathing pattern due to the motor neurone disease.

Wang et al (2005) studied 60 patients (23 with aspiration) who undertook videofluoroscopy examination simultaneously with pulse oximetry. They used a 3% or greater level of desaturation as a measure of aspiration. The group was mixed with stroke, other neurological disorders and ENT subjects within it. The authors found that a 3% or more fall in oxygen saturation produced a sensitivity

of 39.1% and a specificity of 59.4% in the detection of aspiration. The positive predictive value of pulse oximetry in detecting aspiration was 37.5% with a negative predictive rate of 61.1%. When the study further sub divided its groups to look at stroke specifically it was found to have 12 aspirators out of a group of 27 subjects. The sensitivity and specificity of detecting aspiration in this group was 58.3% and 66.7% respectively. The study had a significant flaw. The technique of making thickened and paste food for VF studies should not be by simply adding more barium. Barium is a heavy coating medium designed primarily to outline anatomical anomalies. Barium should be thickened with a recognised food thickener or a substance such as "angel delight" so as not to alter its basic properties. The authors will have potentially produced many false positives even amongst non aspirators by doing what they have done. The barium would have been very cloying and difficult to swallow or pass through the pharynx. This could potentially make any subject breathless. The group also explained that they used only very small amounts of each consistency to test their subjects and stopped if the subject aspirated possibly not allowing the subject to experience desaturation. They conclude that perhaps it is a disordered breathing pattern which contributes to the subject desaturating.

It is clear that the relationship between swallowing and breathing is still not fully understood and this is even more so when the patient either has an impairment in the swallow or in breathing or both. It would appear to be important to find out if the act of disordered swallowing can be shown as a change in the respiratory function of a patient, can this change be detected by routine respiratory measurements and if this could be developed as a clinical tool. The ability of pulse oximetry and or respiratory measurements to detect aspiration potentially could be very useful as a screening tool for this.

1.08 Rationale for study:

Dysphagia is a significant and well recognised problem for people with neurological disease. It is associated with increased mortality, morbidity and reduced recovery. Even though dysphagia and in particular aspiration are well recognised clinical problems, the ability to accurately detect them is still limited. The gold standard videofluoroscopy cannot always be used for the reasons previously stated and other techniques are either not useful in a clinical environment or have poor levels of sensitivity and specificity.

The use of respiratory measurement tools, in particular pulse oximetry, to indicate the presence or absence of aspiration has shown some promise. However previous studies in the use of pulse oximetry as a method of detecting aspiration have been criticised for several reasons. Studies may have only used subjective methods for detecting aspiration such as a speech and language therapist's bedside assessment (Zadi 1995). Studies by Splaingard (1988), Logemann (1993), Horner (1988), Kidd (1993) have all shown that bedside assessments are unreliable in diagnosing aspiration. Between 42% - 60% of aspiration confirmed with nasendoscopy or videofluoroscopy were not identified on bedside assessment.

The size of the study populations has been very small and often studies use patients with mixed pathology or else are single case studies. (Rogers 1993, Sellars 1998). Methods of assessment other than the gold standard (videofluoroscopy) have been used such as auscultation, or nasendoscopy or that the gold standard was not simultaneously performed with pulse oximetry. (Colodney 2000, 2001, Lim 2001). All the studies also found that some subjects despite aspirating considerable amounts of food or fluid did not desaturate and it is unclear why this should be, so it is still not clear if aspiration leads to / or is accompanied by a significant reduction in oxygen saturation.

The Hypothesis

Based on the results of previous studies by Roger (1993), Zadi (1995), Collins (1997) and Smith (2000) it is reasonable to hypothesise that the majority of subjects with neurological dysphagia will show a significant fall from baseline oxygen saturation level if they aspirate. The work of Selley (1989) and Pinnington (2000) has demonstrated that dysphagic subjects also have abnormal breathing patterns after aspirating. These findings suggest that subjects who aspirate may have disordered respiratory function either before or after swallowing as measured by clinical tools of respiratory function. If this is borne out by the evidence, then in turn this could lead to the development of a clinically useful predictive tool.

The present study was designed in conjunction with a medical statistician to overcome the methodological deficiencies of previously reported research. A prospective, controlled, single blind study was designed. It aimed to compare videofluoroscopy simultaneously with pulse oximetry individual pathology types with age and sex matched controls. Respiratory measurements pre and post swallowing were compared and correlated with basic anthropometric measures as potential indicators for aspiration. The data were analysed to look for differences between aspirating and non aspirating subjects within each disease state and as a whole group. The measured variables were then assessed for their use as a sensitive and specific method of detecting aspiration in a clinical situation.

2.00 CHAPTER 2 Methodology Study 1

In this chapter the methodology used to investigate the effects of aspiration on arterial oxygen saturation in the dysphagic patient will be described. The study was approved by the Southampton and South West Hampshire Ethics Committee and the Salisbury Research Ethics Committee. The chapter is divided into the following sections:-

* The Study Design
* Patient Selection
* Patient Recruitment
* The Study Protocol

2.01 The Study Design

This was a prospective controlled single blind study in which multiple respiratory function measures were compared to videofluoroscopy. It was designed in consultation with Sue High, Medical Statistician at the University of Southampton.

The study took place in the radiology suites of Southampton General Hospital and Salisbury District Hospital. All patients were attending a routine videofluoroscopy assessment.

The main purpose of this study was to investigate the effects of aspiration on oxygen saturation levels. The researcher was looking to see if aspirating subjects had a fall of 2% or more in oxygen saturation levels after swallowing. This was in addition to looking for changes (most likely a fall) in respiratory function measurements as measured by spirometry and to look for other non-invasive respiratory markers which may have an influence on dysphagia.

2.02 Patient selection:

Initially permission was sought from the consultant Radiologists at Southampton General Hospital and Salisbury District Hospital to approach their patients and ask if they would participate in the study. In Salisbury District Hospital, as a condition of the local ethical approval, all referring hospital based consultants were asked to give permission for their patients to enter the study. Studies did not run consistently in Southampton and Salisbury due to intermittent lack of funding and other factors within the radiology department such as redecoration and other services being prioritised over videofluoroscopy.

Speech and Language Therapists or the Ear Nose and Throat Department (ENT) surgeons referred patients to the videofluoroscopy clinic. There was an established regular clinic at Salisbury so the majority of patients came from there. Consecutive stroke (acute and established longer than 6 weeks), head injured, multiple sclerosis (M.S.), Huntington 's disease, motor neurone disease (M.N.D.) and Parkinson's Disease (P.D.) patients attending the clinic were approached for their permission to take part in the study. This was initially by the consultant radiologist via a letter sent out with the initial appointment letter. It was recognised that all previous pulse oximetry research had been undertaken with small sample sizes most likely due to difficulties in recruitment and facilities. The intention of the researcher was to "over-sample" and recruit more subjects to increase the power of the study where possible.

A power calculation computed by Sue High demonstrated a sample size of 16 in a group of subjects (aspirating and non-aspirating) would have 80% power to detect a difference of 2% or more using a two group t-test with a 0.05 two sided significance level. This was based on the author's previous work with pulse oximetry and stroke patients. The researcher wished to look not only at the dysphagic population as a whole but at individual disease groups attending videofluoroscopy. It was therefore decided initially to analyse the subject group as a whole, but then to divide it up into separate diseases

(Consecutive strokes, head injured, multiple sclerosis, Huntington's disease, motor neurone disease and Parkinson's disease). If all 7 disease groups were to be analysed a total of 224 subjects (7 x 32) would be required to achieve the same power, assuming 50% were aspirators or equal numbers of aspirators and non aspirators. However given previous sample size difficulties with this population the design was made flexible enough to cope with smaller sample sizes. It was recognised that there may not be enough participants recruited to each disease group and that those individual groups may not be large enough to analyse individually. If this was the case a decision would be made to pool groups together.

A significance level of only p=.05 did increase the chances of type I statistical errors occurring during multiple comparisons so a more stringent significance level was required to increase the confidence and as a result of this p=.01 and p=.005 were considered appropriate. The significance level p=.05 was also included for future direction as this study has only a small sample size and should be considered a pilot if not fully recruited to. A Bonferroni correction was also included where parametric tests were used, and the subgroups were stratified by sex and disorder, to reduce the likelihood of getting a significant result by chance alone.

2.03 The inclusion and exclusion criteria:

For patient selection the inclusion criteria were:

- A clinical diagnosis of 1) stroke (lasting less than 6 weeks but with residual neurological deficit), 2) stroke (greater than 6 weeks from onset, with residual neurological deficit) – these were confirmed by routine CT scan, 3) head injury (confirmed by CT scan), 4)Parkinson's disease (as confirmed by a consultant neurologist or rehabilitation physician), 5)Huntington's disease (confirmed by genetic studies), or 6) multiple sclerosis (as confirmed by a consultant neurologist or rehabilitation physician.

- Perceived difficulty eating or drinking by either a Speech & Language Therapist or member of the Ear Nose and Throat (ENT) staff.
- Aged between 18 - 90 years.

For patient selection the exclusion criteria were:

- Severe uncontrolled Raynaud's disease (sufficient to render an impalpable radial pulse at the wrist at the time of the study).
- Patients with severe dysphasia who were unable to provide informed consent, despite being provided with picture consent forms.

The exclusion of patients with Raynaud's disease was necessary because a finger probe was being used, which would have had difficulty picking up a reliable signal due to impaired peripheral circulation.

2.04 Patient recruitment:

The patients were approached either as outpatients in the ENT or Speech and Language clinics or as in-patients during their stay at one of the two study hospitals once they had been referred for videofluoroscopy assessment.

The patients were initially approached by the consultant radiologist who included an information letter, consent letter (in picture form if the patient was known to be dysphasic) and a prepaid envelope, in the videofluoroscopy appointment letter. If the patient had been an inpatient then a member of staff, who was not the researcher, provided the same information. Outpatients were approached at least 2 weeks prior to the videofluoroscopy, in-patients were asked to consider their decision for 24 hours before their assessment. Patients were asked to get another adult to witness their signature on the consent form.

The patient's general practitioner was not approached as all patients were already under the care of a consultant radiologist who had given consent for

the study to take place using their patients. Full sets of medical notes were available during the study.

Patients were asked to return their witnessed consent forms in pre paid envelopes or they could be returned in the hospital post. If they required further information before consenting there was a telephone number or contact address on the enclosed information letter [appendix B].

Assurances were given that the patient information gathered during the course of the study would be treated as confidential and stored in a secure place. All individual patients' information was archived in line with current ethics committee guidelines.

2.05 Potential bias in patient selection:

The study had potential bias in selection as it was recruiting patients who were attending routine NHS videofluoroscopy assessments. This meant that the patients were considered to be at risk of dysphagia and aspiration by either a Speech & Language Therapist or by a physician. Non aspirating patients were being used as controls. These were patients who were attending videofluoroscopy because of a suspicion by their Speech & Language Therapist that they may be aspirating. If they were not seen to aspirate on videofluoroscopy they were categorised as controls and compared to those patients who did aspirate who were categorised as subjects. However it is recognised that their swallowing may have been disordered even if they did not aspirate on the occasion of the videofluoroscopy. It is however considered inappropriate in this country to carry out videofluoroscopy assessments on "normal" healthy adults because of the radiation dose given. Other studies have tried to compare patients undergoing videofluoroscopy with controls who do not. This is unsatisfactory as it can never be proven objectively what is happening when the control patients swallow. It is automatically assumed that they will have no disorders of swallowing, but especially in the older population this is an unwise assumption.

There was also potential for bias in selection in using patients attending videofluoroscopy at the clinics chosen, because they were all considered well enough to be out of the ward and in a radiology department for approximately an hour. Many of the patients that would be seen routinely by a Speech and Language Therapist for a bedside assessment are extremely unwell and are not capable of being out of a ward environment for any length of time. It could be argued therefore that the group of people which were selected were physiologically healthier. This study did however reflect current clinical practice. Unfortunately most departments do not have the facilities to perform videofluoroscopy at the bedside.

By excluding patients in the study who had profound dysphasia, and were therefore unable to consent, there was a potential weakness in the study as these patients may have specific problems not seen in other subgroups but it would clearly be unethical to recruit people to a study of which they cannot understand the implications.

A particular problem of respiratory studies in people with dysphagia is the lack of standardisation of techniques and practices in both MEP /MIP and spirometry studies. An attempt to overcome this has been made in this study. Patients were given a standardised set of instructions and they were allowed to practice the technique up to 3 times before they undertook a series of 3 attempts. The equipment was calibrated and checked regularly.

2.06 Rationale for the individual components of the study design

Pulse oximetry readings:

The investigator's previous study (Collins 1997) demonstrated a link between aspiration and 2% or more drop in oxygen saturation either at the point of aspiration or in the 2 minutes post aspiration in stroke patients. For this reason pulse oximetry readings were taken continuously during the swallowing assessment.

Spirometry Readings:

Lung volume may be reduced in some conditions which have dysphagia as a symptom. Volume may further be reduced following aspiration or respiratory compromise when eating. If aspiration does lead to bronchoconstriction then it is expected that FEV_1 will fall.

MIP & MEP Readings:

Respiratory muscle strength may be an important factor in the patient's ability to co-ordinate their breathing when swallowing and in their ability to cough and clear should they aspirate.

Ability to Cough:

The ability of a patient to cough voluntarily and spontaneously was recorded. Multiple studies have drawn varying conclusions regarding the ability to cough, the supposition being that patients who are unable to cough spontaneously are more likely to aspirate as they are unable to protect their own airways.

Collar Size:

It has been well documented that people who have a collar size over a size 16-½ (women) /17 (men) inch are prone to sleep apnoea and snoring. This study wished to investigate if there was link with collar size with dysphagia.

Snoring History:

It is well documented that people who snore have a higher risk of sleep apnoea than those who do not. The study wished to investigate whether there was a link between snoring and dysphagia. Patients or their partners gave a snoring history.

2.07 Ethical approval:

There was no need to obtain approval of the Administration of Radioactive Substances Advisory Committee of the DHSS because the videofluoroscopy was part of the patients' usual treatment, administered by a superintendent radiographer or consultant radiologist.

2.08 Protocol:

The study procedure:
Prior to the arrival of the patients, at the videofluoroscopy clinic, the spirometer and mouth pressure monitor were checked for normal functioning. The pulse oximeter was self calibrated and checked to see if it was functioning normally. The probe was cleaned with an alcohol swab prior to use on each patient, the spirometer had disposable mouthpieces with a filter and the flanged mouth pressure mouthpiece was disinfected between each patient.

When the subjects who had given informed consent arrived at the radiology department the investigator greeted the subject, and the study was explained once again. The subjects were sat in a chair in the study waiting area with their arms loosely supported. Subjects then had their neck size measured just below the larynx and perpendicular to the long axis of the neck (Ben-Noun et al 2001) and were asked about their ability to cough spontaneously and voluntarily. They then had 3 attempts at MIP and MEP and spirometry using the equipment described previously. A script giving instructions was given as well verbal encouragement during each measurement. Baseline oxygen saturation levels were then taken. The oximeter's finger probe cable was looped loosely round the wrist to help stabilise the probe head. The probe was attached to the ring finger of the affected hand. If the subject was wearing nail polish this was removed prior to the placement of the probe with a non-alcohol based polish remover. The oximeter was turned away from the subject's view and all alarms were turned off to reduce any anxiety they might

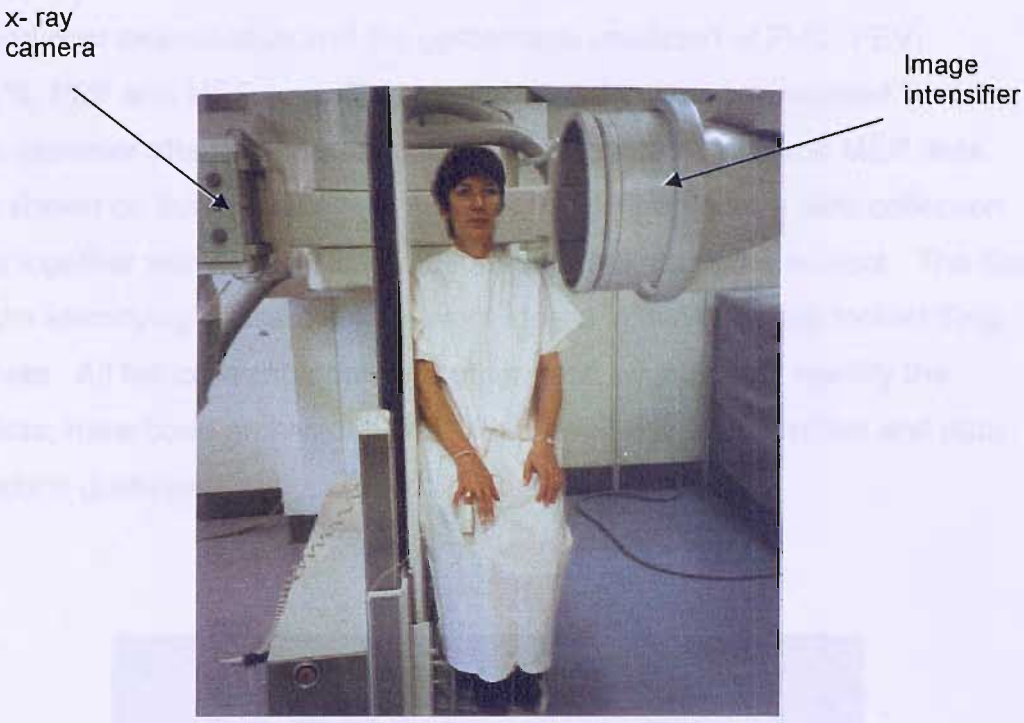
have caused. The patient was instructed not to move the hand with the finger probe so as not to disturb the position of the finger probe. The subjects then sat in the waiting area for a period of at least five minutes before the readings of arterial oxygen saturation were made.

The subject then moved to the examination room either by walking if they were mobile or in a wheel chair. Patients were asked to stand between the fluoroscopy tube. Those who are unable to stand were seated on a Mangar videofluoroscopy chair (see figures 2.01 & 2.02). The oximeter was then allowed to settle again for a period of five minutes before readings were taken. The finger probe was left in place with the machine running while the videofluoroscopy took place.

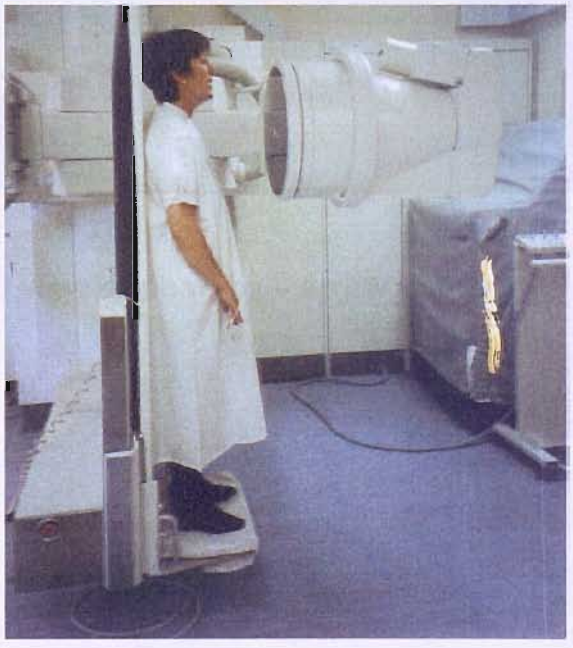
The radio opaque food and drink was given to the subjects under the control of the NHS Speech and Language Therapist and radiology team. Currently there are no standard protocols in either clinic regarding the amounts of barium which the patients are given. However, on average patients swallow 150 mls of liquid barium, 3 oz of mousse with barium impregnated in it and half a 2 inch in diameter shortbread biscuit. If subjects had severe dysphagia then these amounts were reduced appropriately. The images were recorded in lateral and anterior-posterior positions (see figures 2.03 & 2.04). It was noted if there was a difference in saturation levels dependent on which food substance had been swallowed or aspirated.

The final readings were taken in the waiting area 10 minutes after the examination had finished. The examination was reviewed by the NHS team and the timings were matched to the pulse oximeter data output by the researcher.

Videofluoroscopy Suite



Figures 2.01, 2.02 Standing and sitting positions for videofluoroscopy procedure



The data:

Data collected from the spirometer included predicted values, actual values pre and post examination and the percentage predicted of FVC, FEV_1, FEV_1%, PEF and MEF_{25-75}. Pulse oximetry data were downloaded from the pulse oximeter after the fluoroscopy and then printed. MIP and MEP data were shown on the machine and this was transcribed onto a data collection sheet together with all other information recorded about the subject. The data and the identifying consent sheets were stored in two separate locked filing cabinets. All the consent forms and other data, which could identify the subjects, have been archived in line with current ethics committee and data protection guidelines.

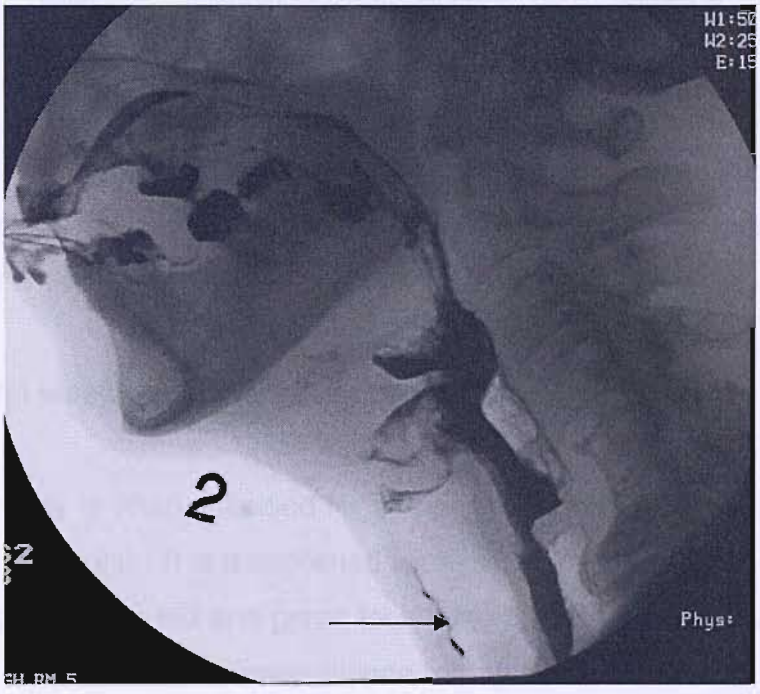


Figure 2.03: lateral view of pharynx – arrow pointing to substance being aspirated

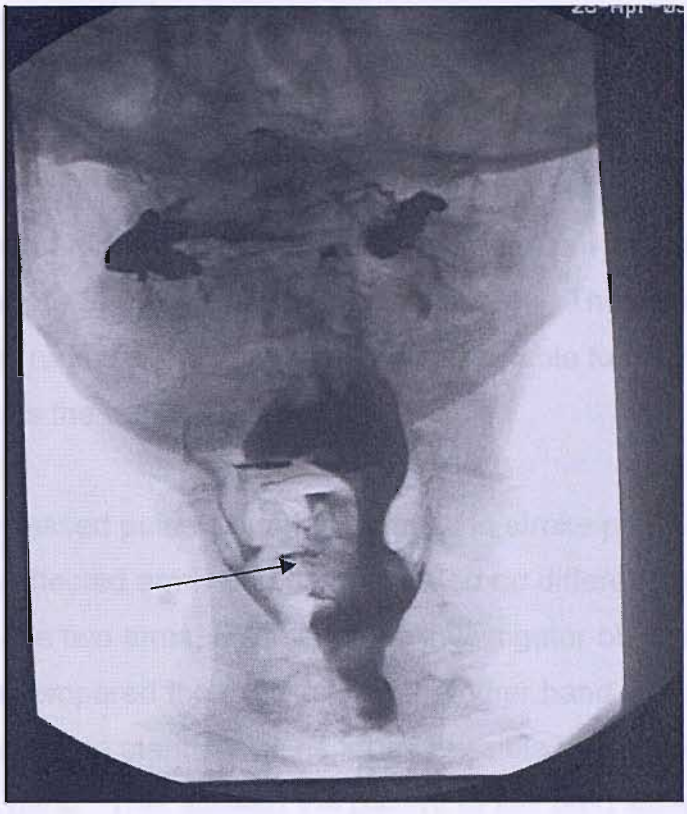


Figure 2.04 : anterior-posterior view of pharynx: arrow pointing to level of vocal folds which are shown up black because they have been coated with barium where a participant has aspirated

2.10 Potential weaknesses in study design:

Videofluoroscopy is often criticised for being an "abnormal" environment in which to eat and drink. It is a darkened room in which the patient is sat upright. They are often fed and given food which is impregnated with barium, a substance which bears no resemblance to any known foodstuff. It is however still considered to be the only gold standard in swallowing assessment. The food which the patient was given was standardised across the two Trusts undertaking the studies. The only objective method of investigation which uses food which has been unaltered is nasendoscopy. This however involves passing an endoscope into the nasopharynx. By doing this the patients airways are altered which could alter the way that they swallow. It was also considered unacceptable for this study as it is impossible

to see where the food stuff goes at the point of swallow because the camera is "whited out."

The interpretation of the videofluoroscopy results carried out by at least two experienced and competent NHS staff, who were not privy to the respiratory measures taken pre and during the videofluoroscopy. The investigator was positioned in the radiology suite so that she was unable to view the study and so potentially bias the result.

Roffe (2001) assessed pulse oximetry readings in stroke patients comparing affected with unaffected arm. She demonstrated no differences in saturation levels between the two arms; however if the investigator observed a reading below 90% she compared the reading with the other hand and adopted the higher. In this study, to standardise as far as possible the probe was placed on the affected hand. This allowed the patient to self feed where possible and reduced the potential for movement artefact.

2.11: Data Analysis

The following statistical analyses were used:

1. The data collected in this study were used to show method comparison between pulse oximetry and the "gold standard" videofluoroscopy. This comparison was made using Kappa (k) statistics.
2. The data were used to show comparison between spirometer measurements before and after the act of swallowing. This comparison was made using paired t-tests and Mann-Whitney U tests. Further Kappa statistics were applied to look for method comparisons between spirometry measurements and videofluoroscopy.
3. The data were used to show the proportion of patients who have a history of smoking and snoring and the distribution of their collar size. This measurement was made using X^2 statistic.
4. A multiple regression was then undertaken to analyses the influence of the above factors on the ability to swallow.

5. 5. A CHAID analysis was undertaken to further examine the influence of smoking, oxygen saturation levels, snoring and collar on swallowing.

The tests were performed using the statistical computer programmes SPSS 11.00 and Answer Tree version 2. The criterion for statistical significance was that total agreement was present when [k value] was equal to one or that when p value was equal to or less than 0.05. When k = 0 this indicates no agreement better than chance. When p = greater than .05 this indicates no statistical significance at the 5% level. Sensitivity will be described as the probability of a positive test amongst patients with dysphagia. Specificity will be described as the probability of a negative test amongst patients without dysphagia. This is summarised in the table 2.01.

Table 2.01 Equation for calculating sensitivity and specificity

	Patients with aspiration	Patients without aspiration
Test is positive	a True Positive	b False Negative
Test is negative	c False Negative	d True Negative

Sensitivity = a / (a + c)
Specificity = d / (b + d)

The clinical significance of the results will be discussed in Chapter 4.

CHAPTER 3: RESULTS STUDY 1

3.00 Introduction:

This chapter presents the results of the study into the effect of aspiration on arterial oxygen saturation level. The additional variables of smoking history, collar size, the ability to produce cough and measures of lung function were all recorded to examine any association between them and with videofluoroscopy findings in patients with neurogenic dysphagia.

3.01 Subject Characteristics:

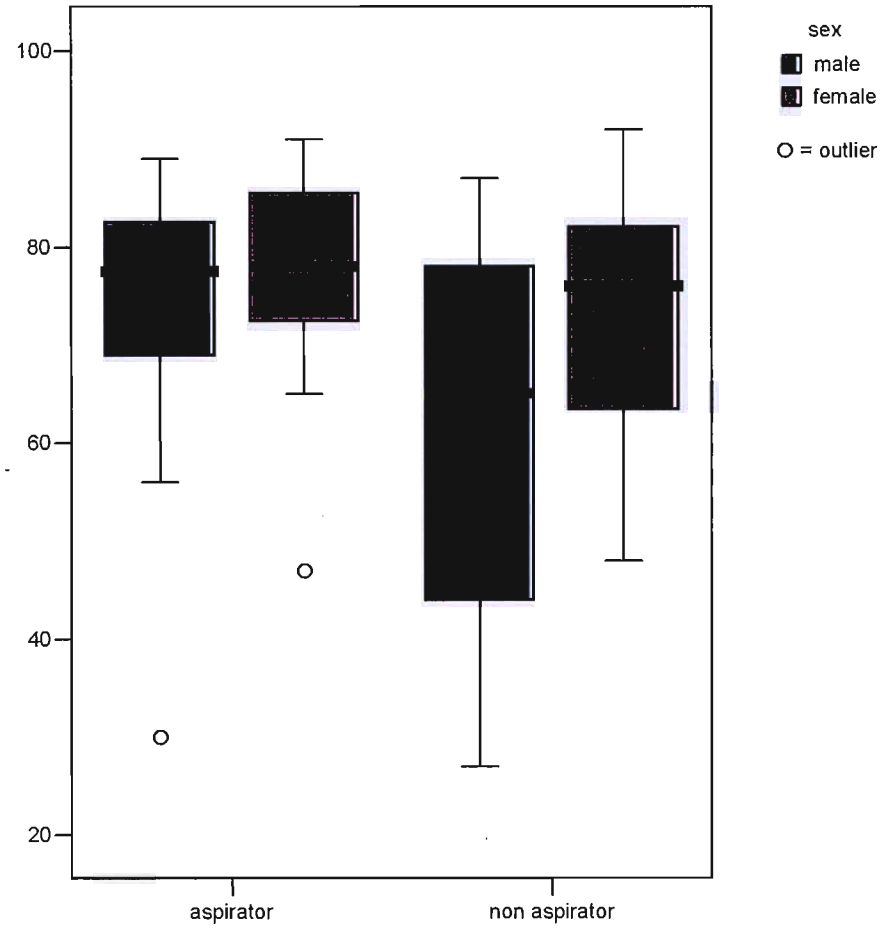
A minimum number of 32 subjects, for each subgroup, equally divided between aspirating and non aspirating subjects would have been required to detect a 2% difference in oxygen saturation and provide 80% power. In practice a total of only 76 consecutive subjects (43 aspirators and 33 non aspirators) fulfilling the study criteria, entered and completed the study out of a recommended 227. This means that this study is underpowered and should be considered a pilot study. The results interpreted with caution due to the small number sizes.

There were 46 male and 30 female subjects with a variety of neurological conditions. The subjects' characteristics are summarised in the tables 3.01.01, 3.01.02 and figure 3.01.01. The raw data from which these results are derived can be found in appendix number F -01.

Table 3.01.01 Age Characteristics of aspirating and non aspirating subjects (whole group):

Age (yrs)	Whole	Aspirators		Non-Aspirators	
	Group	Male	Female	Male	Female
Mean	71.64	74.39	77	61.39	73.47
Std. Dev.	14.75	12.12	11.24	18.32	12.82

Figure 3.01.01 Box and whisker plots showing median and interquartile ranges of age distribution of subjects.



Subjects in the aspirating group were significantly older than in the non aspirating group (p=.018). When this was analysed further by looking at sex of the subject as a variable, as well as aspiration, it is seen that there was a statistically significant difference in age between the male groups (p=0.13) but not between the women (p=.43) see figure 3.01.01. When looking for a 2% difference in oxygen saturations as an indicator of aspiration the study had 80% power (p=.007) to find a difference in the male aspirating and non aspirating subjects. The study was not adequately powered to find a difference between the female aspirating and non aspirating subjects with only 14% power (p=.390).

Table 3.01.02 Summary of disorders in aspirating and non aspirating subjects by disease

Disorder	Aspirator		Non Aspirator		Total
	Male	Female	Male	Female	
Acute stroke	1	3	1	1	6
[1]S/acute stroke	22	10	9	9	50
Parkinson's	3	2	4	1	10
[2]M.S.	0	0	1	2	3
[3]M.N.D.	1	0	2	2	5
Head Injury	1	0	1	0	2

1.Sub Acute, 2 .Multiple Sclerosis, 3. Motor Neurone Disease

When the trial was first conceived, the idea had been to study a number of pathologies to compare patterns of oxygen saturation during videofluoroscopy. Due to the small group size in some of the disorders it was decided to pool participants together into two pathologies, stroke and mixed neurology. There were 56 subjects in the stroke group and 20 in the mixed neurology group. The data were then analysed to compare these two groups. It was found that there were no statistically significant differences between aspirators and non aspirators within the two groups.

Only the mixed neurology group had sufficient recruits to provide adequate power to detect a difference of 2% or more change in oxygen saturation level from baseline (stroke group p= .48, power of 48% and neurology group p=.008 power of 80%). The stroke group would have required 110 subjects to provide power of 80%. This means that any data from this study should be interpreted cautiously but has been included here as it may give direction to future studies.

The two pathology groups were further analysed by sex as well as aspiration and no statistical significant differences were found between groups, but this may have been due to the small size of the groups. Retrospective power calculations were carried out, using a univariate analysis of variance. Each of the groups which had been divided by sex and disorder had a retrospective power calculation performed and this showed the only group with statistical power to detect a 2% or more change

in oxygen saturation level from baseline were male stroke subjects p=.009 with a statistical power of 77%.

Table 3.01.03 Summary of subjects by stroke type

Aspirator Non aspirator	Stroke	Stroke type	Male	Female
Aspirator	acute stroke	Other	1	
		Right MCA		1
		Not recorded		2
		Total	1	3
	Sub acute	Right MCA	1	5
		Left MCA		1
		posterior	3	
		lacunar	1	
		brainstem		1
		Small vessel disease	1	
		Other	1	2
		Not recorded	15	1
		Total	22	10
Non Aspirator	Acute stroke	lacunar	1	
		Not recorded		1
		Total	1	1
	Sub acute	right MCA	1	1
		Left MCA	2	1
		lacunar	1	2
		brainstem	3	
		Not recorded	2	5
		Total	9	9
Totals			33	13

MCA = middle cerebral artery

3.02.00 Videofluoroscopy results

A total of 76 subjects underwent pre and post videofluoroscopy, spirometry and simultaneous pulse oximetry (56 stroke and 20 mixed neurology). Videofluoroscopy indicated that 28 out of 46 (61%) men and 15 out of 30 (50%) women were aspirators. A silent aspirator was defined by the videofluoroscopy team as a patient who showed no obvious signs of distress when any amount of food or fluid passes through the laryngeal vestibule and into the trachea. Videofluoroscopy demonstrated that 21 out of 28 (75%) of the aspirating men and 14 out of 15 (93%) of aspirating women did so silently.

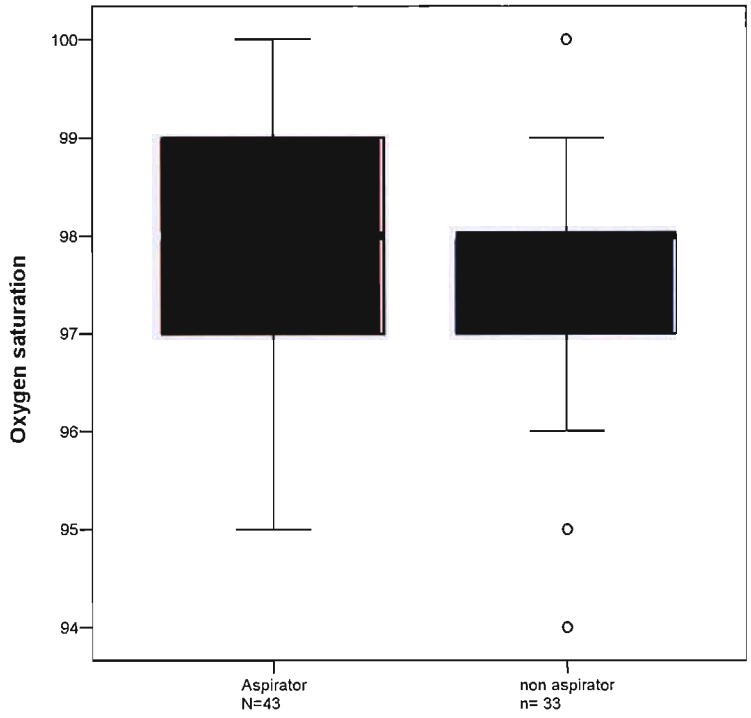
3.03.00 Pulse oximetry results

Although baseline oxygen saturation levels were recorded both inside and outside the examination room, for the purposes of clarity only the results recorded inside the examination room will be shown, as there was no difference in baseline in any sub-groups. The pulse oximeter collected data automatically every 5 seconds. The oximeter, when downloaded using Score Software, provided this information and also the highest and lowest reading during the examination in a standardised readout. The information displayed in table 3.03.01 and figures 3.03.01 - 03 shows arterial oxygen saturation levels recorded at baseline (the lowest point was taken) and at the lowest point during the swallowing examination.

Table 3.03.01. Whole Group: Mean (standard deviation) oxygen saturation levels pre, post videofluoroscopy (VF), and their mean difference, in aspirating and non-aspirating subjects:

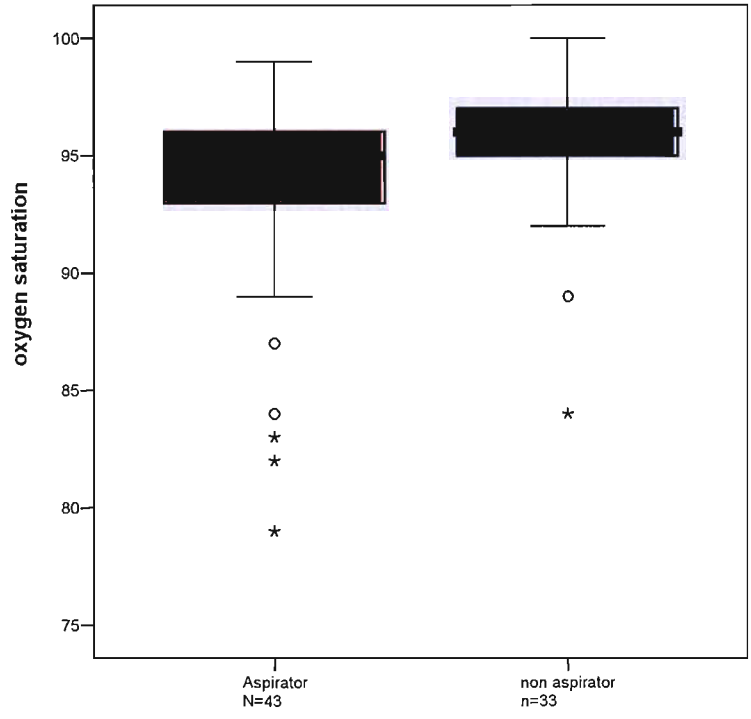
Oxygen Saturation Level %	Aspirator	Confidence Intervals	Non Aspirator	Confidence Intervals
Pre VF O_2	98.09 (1.17)	97.73-98.45	97.58 (1.44)	97.07-98.09
Post VF O_2	93.44 (4.47)	92.07-94.82	95.43 (2.98)	94.37-96.48
Mean difference between pre and post VF	4.67 (4.43)	3.28-6.02	2.18 (2.3)	1.37-3.00

Figure 3.3.01: Box and whisker plots showing median and interquartile ranges pre videofluoroscopy oxygen saturation levels for whole group, divided into aspirators and non aspirators



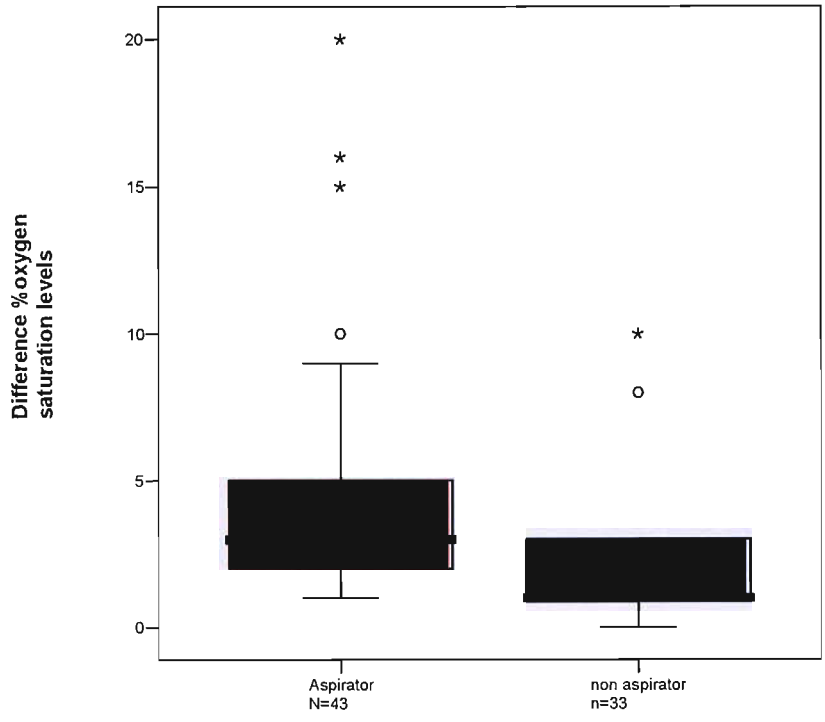
O = outlier

Figure 3.03.02 Box and whisker plots showing median post videofluoroscopy oxygen saturation levels for whole group divided into aspirators and non aspirators.



O = outlier
*= extreme outlier

Figure 3.03.03 Box and whisker plots showing median and interquartile ranges of the difference in % oxygen saturation levels after videofluoroscopy in whole group divided into aspirators and non aspirators



O = outlier
✶= extreme outlier

The data were analysed using Mann-Whitney U tests were used to look for differences within each group (aspirators and non aspirators).

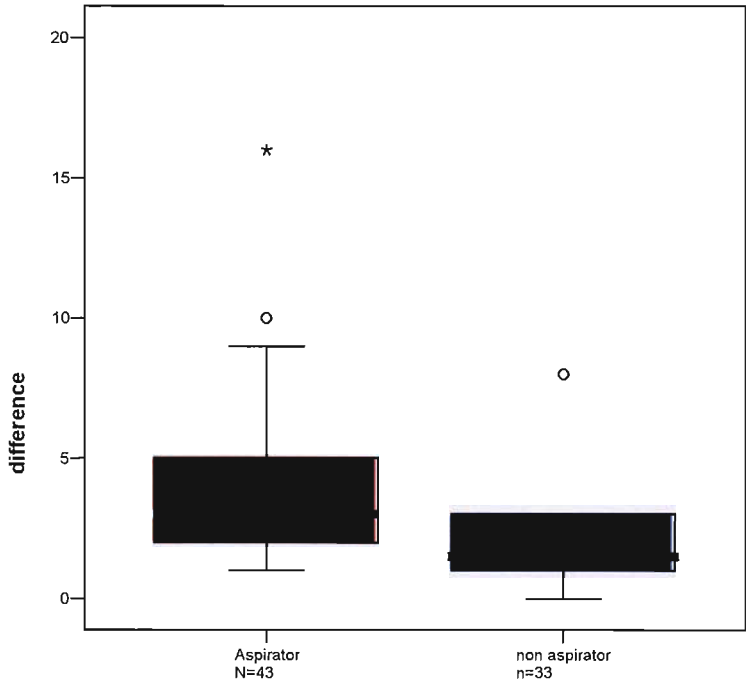
Table 3.03.02 Mann-Whitney U test - whole group. Comparing aspirating and non aspirating subjects' oxygen saturation levels pre and post videofluoroscopy (VF) within groups

Pre compared with post VF	Mean Difference %	Std. Deviation	95% Confidence Interval of the Difference		z	Sig. (2-tailed)
			Lower	Upper		
Aspirator N=43	4.65	4.43	3.29	6.01	-5.731	.000
non aspirator n=33	2.15	2.32	1.33	2.97	-4.778	.000

Table 3.03.03. Mann-Whitney U tests - stroke and neurology groups. Comparing aspirating and non aspirating subjects' oxygen saturation levels pre and post videofluoroscopy (VF) within groups

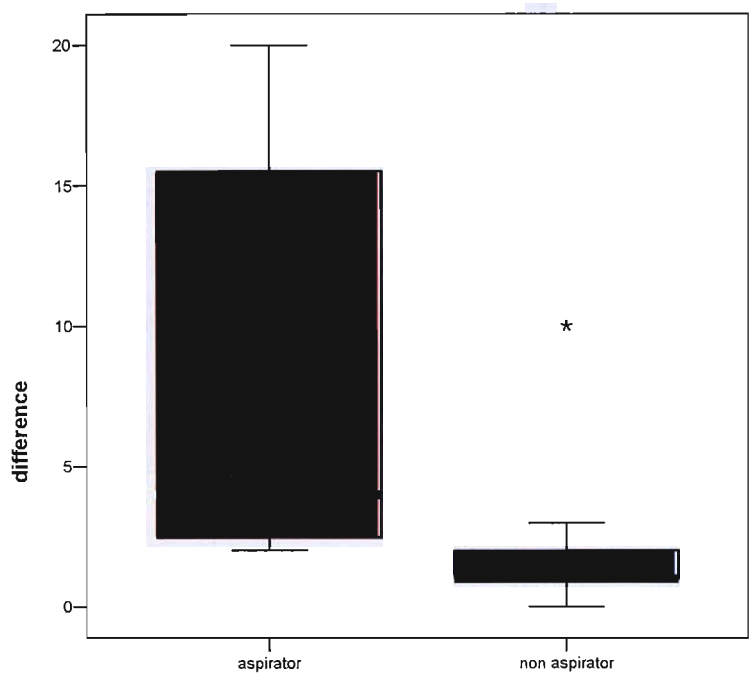
Pre compared with post VF		Paired Differences				z	Sig. (2-tailed)
		Mean Difference %	Std. Dev	95% Confidence Interval of the Difference			
				Lower	Upper		
Aspirator	Stroke n=36	3.83	2.98	2.83	4.84	-5.251	.000
	Neurology n=7	8.86	7.80	1.65	16.07	-2.371	.018
Non Aspirator	Stroke n=20	2.35	2.16	1.34	3.36	-3.885	.000
	Neurology n=13	1.85	2.61	.27	3.42	-2.848	.004

Figure 3.03.04: Box and whisker plots demonstrating median and interquartile range differences in % oxygen in saturation levels after videofluoroscopy in the stroke group



O = outlier
✶= extreme outlier

Figure 3.03.05: Box and whisker plots demonstrating median and interquartile range differences in % in oxygen saturation levels after videofluoroscopy in the neurology group



✶= extreme outlier

The data were further analysed to assess the sensitivity and specificity of using a 2% fall from baseline oxygen saturation level as a method of detecting aspiration. The data is first assessed as a whole group then sub divided into stroke groups and neurology groups.

Table 3.03.04 Predictive values of 2% or more fall from oxygen saturation baseline as an indicator of aspiration

	Negative Predictive Value	Positive Predictive Value	Sensitivity	Specificity
Whole group N= 76	78.3%	71.7%	88.4%	54.5%
Stroke group N=56	66.66%	75.6%	86.11%	50%
Neurology Group N=20	100%	58.33%	100%	61.5%

Data from the whole group demonstrate that there is a statistically significant mean difference in the oxygen saturation levels after swallowing between aspirating subjects and non aspirating subjects (see figure 3.03.03 and table 3.03.02) but the confidence intervals are quite wide. Aspirating subjects have a larger mean fall in saturation levels from baseline than those who do not aspirate (4.7% compared with 2.2%) (see figure 3.03.01). When further analysed if a 2% or more fall from baseline saturation levels is used as a detector of aspiration it has an 88.4% sensitivity and 54.5% specificity (see table 3.03.04). These data were analysed using the Kappa statistical test using a 2% or more fall from baseline as an indicator of aspiration compared with the gold standard videofluoroscopy. A moderate agreement k=0.45 was found (see table 3.03.05).

Table 3.03.05 Measure of agreement using Kappa's coefficient comparing oxygen saturation with videofluoroscopy as a means of assessing aspiration

	Measurement of Agreement Kappa
Whole Group	K = 0.45
Stroke Group	K=0.38
Neurology Group	K=0.53

Data for subjects who were in the stroke group were analysed separately (see tables 3.3.04 and 3.3.05). No statistically significant difference in baseline oxygen saturation levels was found between aspirating and non aspirating stroke subjects. The aspirating stroke subjects were found to have lower saturation levels than non aspirating subjects post swallowing but this was not statistically significant. Aspirating stroke subjects desaturated more than non aspirating stroke subjects; on average 3.86% compared with 2.35% (see figure 3.03.03 and table 3.03.03). A 2% or more fall from baseline oxygen post swallowing as an indicator of aspiration had a sensitivity of 86.11% and specificity of 50% (see table 3.3.04). Using the Kappa statistic comparing a fall in oxygen saturation as an indicator of aspiration against the gold standard gives the value k=0.38, a fair agreement (see table 3.3.05).

Data for subjects who had mixed neurological conditions other than stroke were also analysed separately. No statistically significant difference in baseline oxygen saturation levels was found between aspirating and non aspirating neurological subjects. The aspirating neurological subjects were found to have lower saturation levels post swallowing than non aspirating subjects. Neurological subjects desaturated on average 8.86% compared with 1.5% (see table 3.03.03 and figure 3.03.04). A 2% or more fall from baseline oxygen post swallowing as an indicator of aspiration had a sensitivity of 100% and specificity of 61.5% (see table 3.3.04). Using the Kappa statistic comparing a fall in oxygen saturation level against the gold standard gives a measurement of k=0.53 a moderate agreement (see table 3.3.05).

Comparison of differences in oxygen saturation levels in aspirators and non aspirators by gender:

The data were further analysed by gender. However, univariate analysis of variance demonstrated that the study was only adequately powered to show any difference in males, and even then the samples sizes were very small, therefore the data are shown below are largely for the male subjects. Female data can be found in appendix F-02 of this study. Given the small samples sizes results should be interpreted with caution.

Table 3.03.06a. Mean and standard deviation of oxygen saturation levels, pre and post videofluoroscopy (VF) and their mean difference in males and female, aspirating and non aspirating subjects:

Oxygen saturation level (mean %)	**Aspirator**					
	Male n= 28			**Female n = 15**		
	O_2	S.D.	Confidence Intervals	O_2	S.D.	Confidence Intervals
Pre VF O_2 saturation	98.40	1.12	97.61-98.46	98.20	1.32	97.47-98.93
Post VF O_2 saturation	92.75	4.60	90.97-94.53	94.73	4.06	92.48-96.98
Mean difference between pre and post VF	5.32	4.71	3.50-7.15	3.47	3.71	1.34-5.56

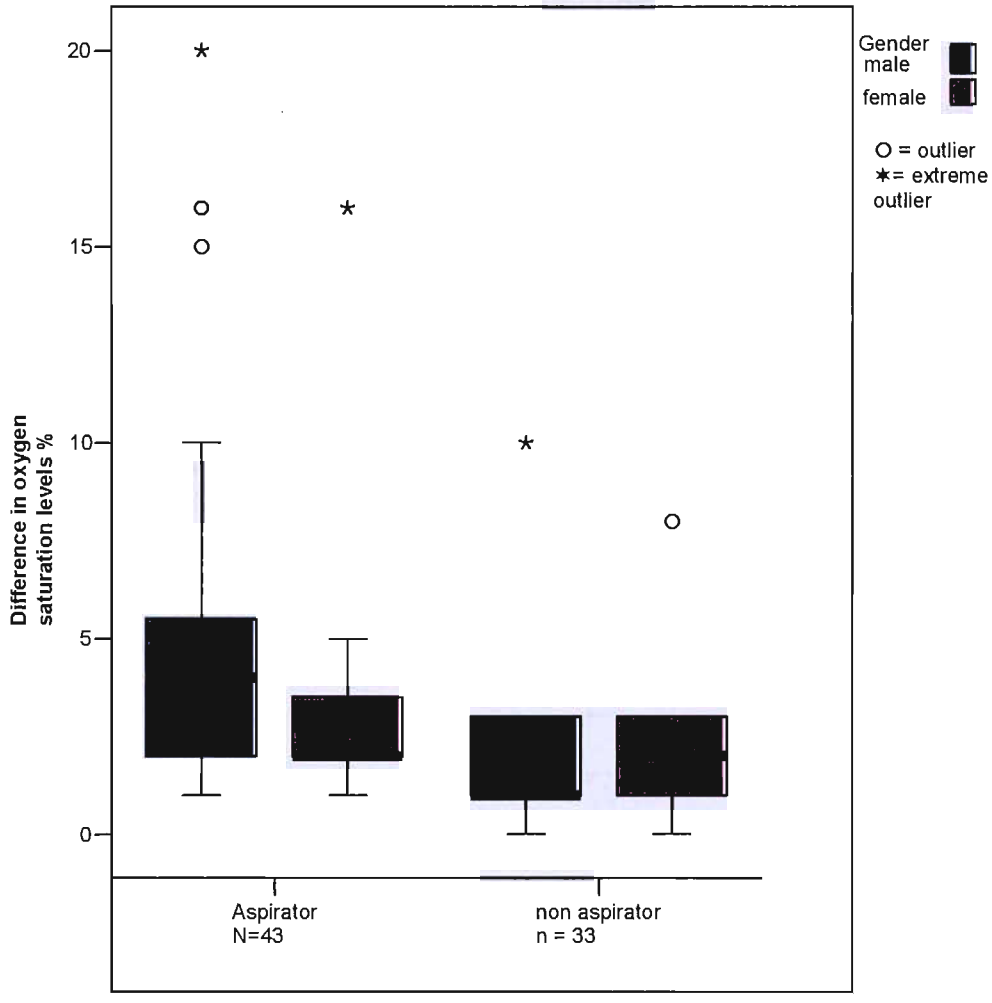
Table 3.03.06b. Mean and standard deviation of oxygen saturation levels, pre and post videofluoroscopy (VF) and their mean difference in males and female, aspirating and non aspirating subjects:

Oxygen saturation level (mean %)	Non Aspirator					
	Male n = 18			Female n = 30		
	O_2	S.D.	Confidence Intervals	O_2	S.D.	Confidence Intervals
Pre VF O_2 saturation	97.50	1.47	96.77-98.23	97.67	1.45	96.87-98.47
Post VF O_2 saturation	95.56	3.35	93.89-97.22	95.27	2.58	93.84-96.69
Mean difference between pre and post VF	1.94	2.01	.85-3.04	2.47	2.45	1.11-3.82

Table 3.03.07 *Whole group by gender*: Mann- Whitney U: Comparing aspirating and non aspirating subjects' oxygen saturation levels pre and post videofluoroscopy (VF) within groups

Pre and post VF		Paired Differences				z	Exact sig.
Group	Gender	Mean Difference %	Std. Deviation	95% Confidence Interval of the Difference			
				Lower	Upper		
Aspirator	Male n= 28	5.286	4.713	3.458	7.113	-4.634	.000
	Female n=15	3.467	3.701	1.417	5.516	-3.428	.001
Non aspirator	Male n=18	1.944	2.209	.846	3.043	-3.744	.000
	Female n=30	2.400	2.501	1.015	3.785	-3.082	.002

Figure 3.03.06. Box and whisker plots demonstrating median and interquartile ranges mean difference in oxygen saturation after videofluoroscopy in whole group when divided by gender



Whole group:

Further analysis of oxygen saturation levels, by disorder and by sex was undertaken. As stated previously the power to detect differences was reduced due to the size of the groups and should be regarded as pilot data to give direction to a larger, fully powered study. When the whole cohort was analysed it was found that aspirating men had a greater drop in oxygen saturation levels from baseline than either aspirating women or non aspirating men or women (see tables 3.03.06 and 3.03.07 and appendix F figures-F.01 and F-02 and tables F-02). Mann-Whitney U

tests demonstrated significant differences in oxygen saturation levels within groups comparing before and after swallowing in both sexes for aspirating and non aspirating subjects (see table 3.03.07 and F-02 and figure 3.03.06).

The kappa statistic was applied to measure a fall of 2% or more fall in oxygen saturation from baseline as an indicator of aspiration against the gold standard videofluoroscopy and demonstrated a good agreement (k=0.62) in men, but a poor agreement in women (k=.20). The agreement may be poor in women due to a genuine lack of agreement or because the study did not have adequate power to show a statistical difference.

Table 3.03.08: Male stroke group: Mann-Whitney U test: Comparing aspirating and non aspirating subjects' oxygen saturation levels pre and post videofluoroscopy (VF)

Mean Difference between pre and post VF	Paired Differences				z	Exact Sig
	Mean Difference %	Std. Deviation	95% Confidence Interval of the Difference			
			Lower	Upper		
Aspirator n= 28	4.61	3.38	3.15	6.07	-4.207	.000
non aspirator n= 18	1.60	.97	.91	2.29	-2.919	.004

Summary of comparison of differences in oxygen saturation levels by disorder and gender:

Stroke group:

The stroke group were then analysed separately by aspiration and by gender. All male stroke subjects had statistically significant changes in oxygen saturation level after swallowing as shown by Mann-Whitney U test (see table 3.03.08). A further higher powered study is needed to investigate these findings more fully as it is likely that a small sample size was the reason for these results.

The Kappa statistic was applied using 2% or more fall from baseline oxygen saturation levels as an indicator for aspiration compared with videofluoroscopy in men gave a good agreement k=.63.

Neurology group:

The neurology group were analysed separately. In the neurology group both male groups (aspirating and non aspirating) demonstrated a statistically significant fall in oxygen saturation levels after swallowing as shown by Mann-Whitney U tests (see table F-02). As with the stroke groups small sample size should be considered a possible reason for these results.

The Kappa statistic was applied using a 2% or more fall from baseline as an indicator of aspiration compared with videofluoroscopy gave a moderate agreement in men k=.56 and women k=.46. As previously stated the study did not have adequate power to find a statistically significant difference in the findings for the neurological group if it was divided by gender.

3.04 The spirometry results for the whole group:

The spirometer used in this study produces a predictive measurement for each subject from the information inputted into the spirometer by the investigator (age, gender, height, and ethnicity). This information is then compared automatically to the actual measurement from the subject's trials. These data are given as a percentage of the predicted. This information can be found in table 03.04.01. Information can then also be printed, for an example (see figures 3.04.01 and 03.04.02). Tests of normality were undertaken comparing predicted baseline measurements against actual pre videofluoroscopy measurements. Within the whole group there were no statistically significant differences between the predicted baseline spirometry measurements (as based on age, gender, height and ethnicity) and the actual baseline spirometry measurements taken before the videofluoroscopy.

Table 3.04.01: (Whole group): Baseline spirometry measurements in aspirating and non aspirating subjects' % achieved of %predicted.

Spirometry Measurement		Aspirators N=39	Non aspirators N=28
FVC	Pre videofluoroscopy	71.73	77.53
	Post videofluoroscopy	74.95	77.60
	Difference (SD)	1.62	.03
FEV_1	Pre videofluoroscopy	61.62	68.60
	Post videofluoroscopy	59.23	67.33
	Difference (SD)	-2.08	-1.27
FEV_1%	Pre videofluoroscopy	92.24	90.87
	Post videofluoroscopy	84.69	88.67
	Difference (SD)	-6.43	-2.10
PEF	Pre videofluoroscopy	40.22	48.73
	Post videofluoroscopy	34.41	48.20
	Difference (SD)	-6.38	-.37
MEF_{25-75}	Pre videofluoroscopy	47.11	50.77
	Post videofluoroscopy	38.59	49.33
	Difference (SD)	-8.61	-2.23

Figure 3.04.01: Output data from spirometer showing raw data from aspirating patient

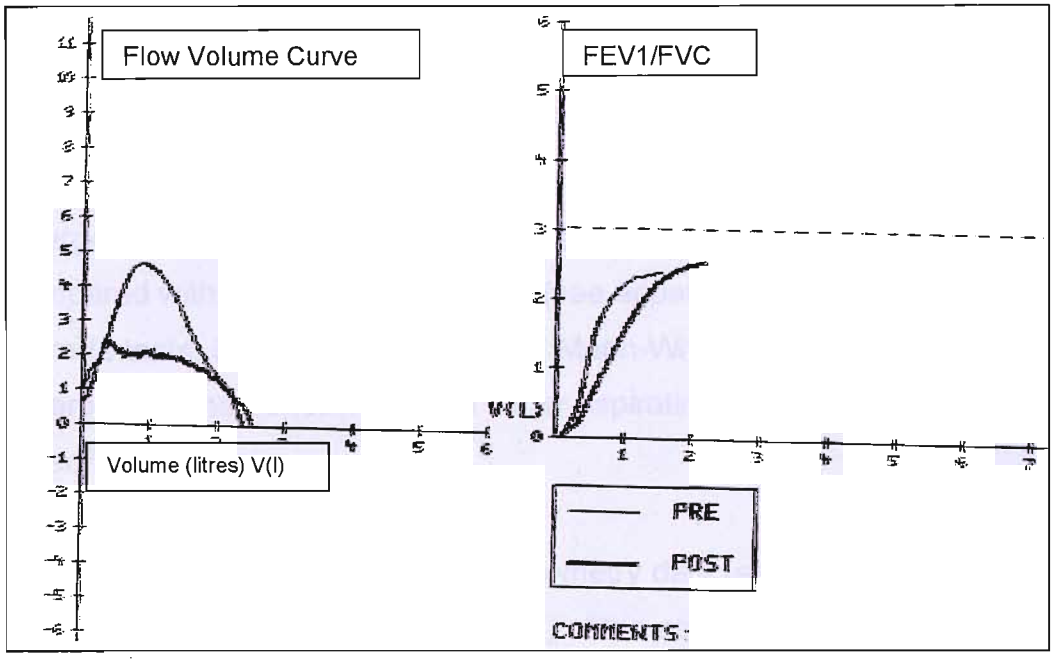
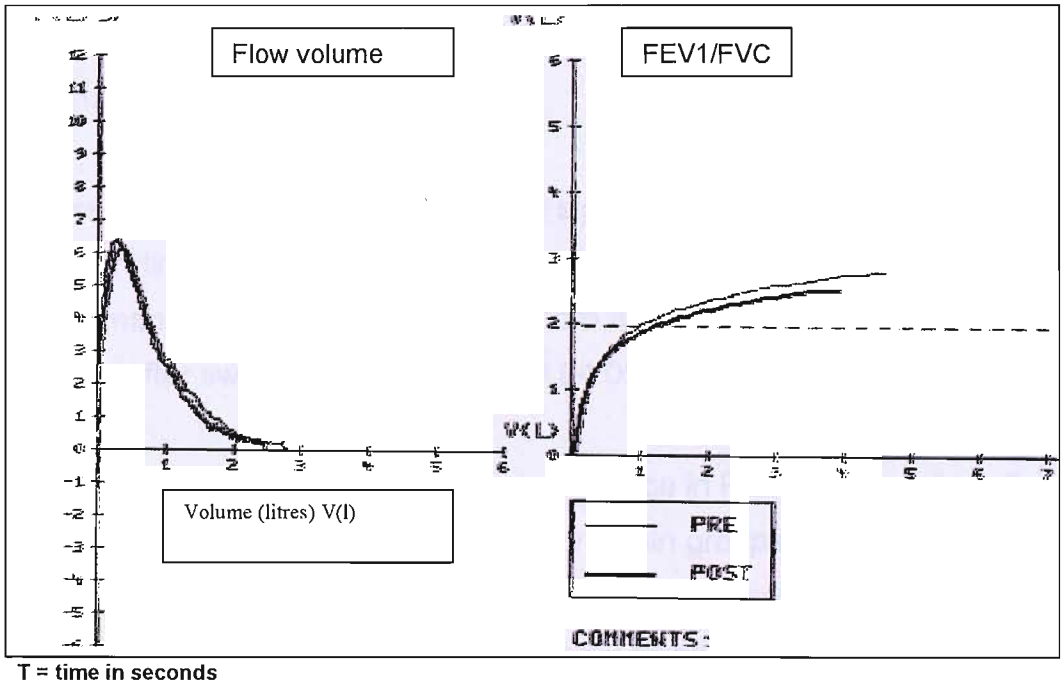


Figure 3.04.02: Output data from spirometer showing raw data from a non aspirating subject



T = time in seconds

All subjects who where physically able, took part in spirometry testing (n=67) (39 aspirators, 28 non aspirators). There were 9 (6 sub acute stroke, 1 motor neurone disease, 1 acute stroke, 1 Parkinson's disease) patients who were unable to complete these tests due to extreme tiredness post procedure or who were severely dyspraxic and unable to co-ordinate breathing into the apparatus. The data were initially analysed as a whole group then in two groups (stroke and neurology).

A large number of subjects (aspirating and non-aspirating) performed poorly compared with their predicted scores (see appendix F-07). When analysed using paired t-tests, independent t-tests and Mann-Whitney U tests there was no statistical difference in the performances of either aspirating or non aspirating subjects prior to videofluoroscopy.

Percentage measurements of the spirometry data (as measured against the spirometer's predicted measurements) of the aspirating and non aspirating subjects in the whole group were then compared with tests of normality for normal distribution. The FVC and FEV_1 were found to be normally distributed and so the aspirating and non aspirating groups were analysed for within group differences using paired t-tests and independent t-tests comparing spirometry measurements before and after swallowing. The remaining tests of respiratory function FEV_1%, PEF and MEF_{25-75} were analysed using non-parametric tests as they were not normally distributed.

There was found to be no statistically significant difference in FVC between groups of aspirating and non aspirating subjects (see table F-03). The aspirating group's performance improved very slightly more after swallowing than the non aspirating groups after swallowing (see table 03.04.01).

There was found to be no statistical difference in FEV_1 between baseline and after swallowing compared either between or within groups of aspirating and non aspirating subjects (see tables 03.04.03 and F-03) both of whom demonstrated a fall in FEV_1. However there was a statistically significant difference in aspirators post swallowing FEV_1% measurement (p=.011) after swallowing compared with non aspirators (see table 03.04.01 and figure 03.04.04). There was also a statistically

significant difference between the post swallowing measurements of PEF of aspirators and non aspirators (p=.007) (see table 03.04.02) and in MEF_{25-75} scores between aspirating (-8.61) and non aspirating subjects (2.23) p=.002 (see table 03.04.02).

To explore how large a study would need to be to be fully powered using spirometry measurements as a means of detecting aspiration a univariate analysis of variance was undertaken to assess the power of the study using the mean difference of FEV1% and PEF. The power of FEV1% as an assessment of aspiration was p=.047 or 51% requiring a study size of 202 subjects to increase the power to 80%. The power of PEF as an assessment of aspiration was p=.043 giving a power of 53%. To use PEF as an assessment of aspiration the sample size would need to be increased to 510 which would increase the power to 80%.

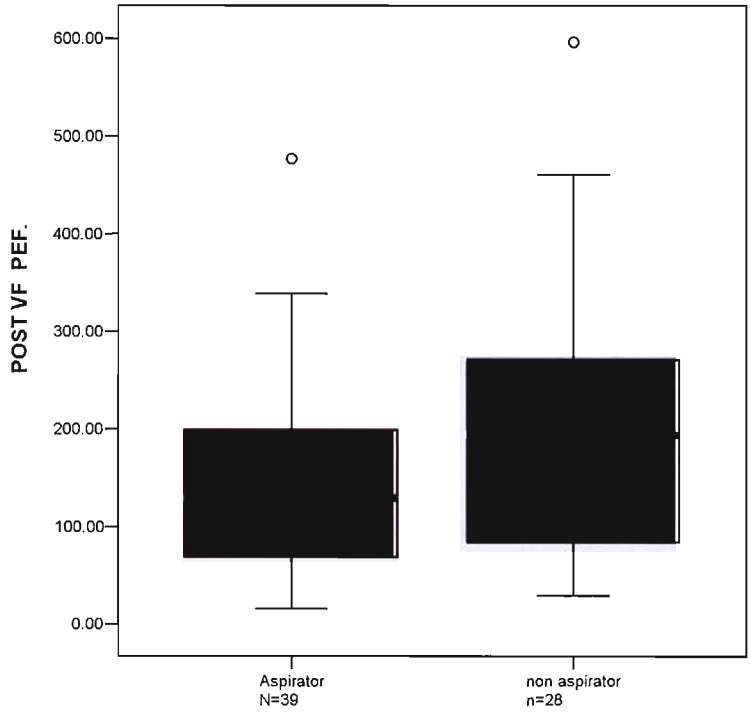
Table 03.04.02: Whole Group Mann-Whitney U tests comparing aspirating and non aspirating subjects' spirometry measurements pre and post videofluoroscopy within groups

Pre minus post videofluoroscopy		Paired Differences					
		Mean	Std. Deviation	95% Confidence Interval of the Difference		z	Exact sig.
				Lower	Upper		
Aspirator N=39	FEV_1%	4.89	12.98	.57	9.22	-2.551	.011
	PEF	27.08	63.78	5.82	48.35	-2.717	.007
	MEF_{25-75}	-2.65	17.68	-8.54	3.25	-3.072	.002
Non aspirator N=28	FEV_1%	1.60	13.14	-3.31	6.51	-.606	.545
	PEF	3.20	54.25	-17.06	23.46	-.151	.880
	MEF_{25-75}	.060	.50	-.13	.25	-1.083	.2.79

Table 03.04.03: (Whole Group) Paired t-tests comparing aspirating and non aspirating subjects' spirometry measurements pre and post videofluoroscopy within groups

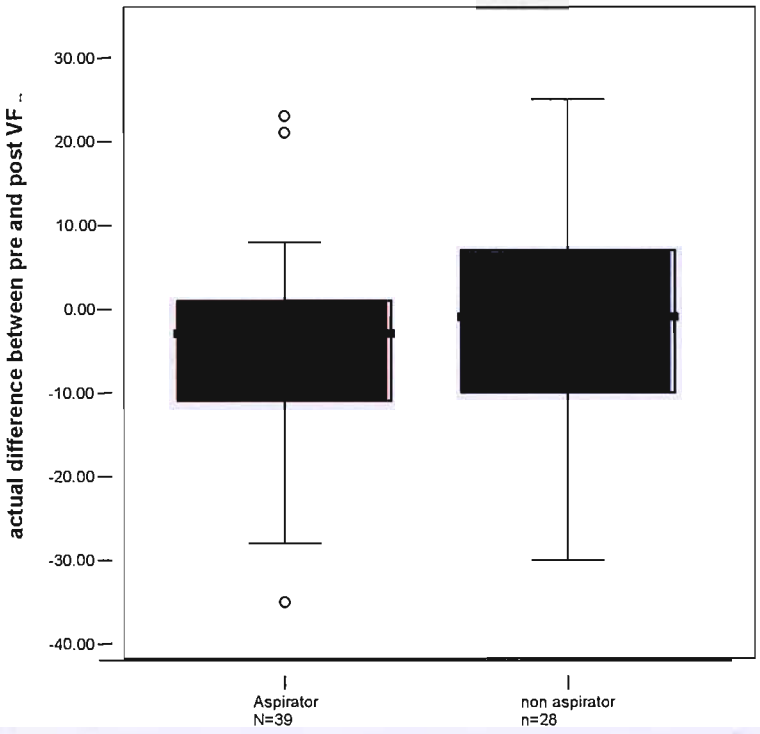
Pre minus post videofluoroscopy		Paired Differences				t	Sig. (2-tailed)
		Mean	Std. Deviation	95% Confidence Interval of the Difference			
				Lower	Upper		
Aspirator N=39	FVC	-1.973	12.5	-6.141	2.195	-.96	.343
	FEV_1	3.081	13.084	-1.281	7.443	1.432	.161
Non aspirator N=28	FVC	-.067	13.653	-5165	5.032	-.027	.979
	FEV_1	1.267	14.468	-4.135	6.668	.48	.635

Figure 3.04.03 Box and whisker plots showing median and interquartile ranges for PEF measurements of aspirating and non aspirating subjects, taken after videofluoroscopy (VF)



O = outlier

Figure 3.04.04 Box and whisker plots showing median and interquartile ranges for FEV_1% measurements of aspirating and non aspirating subjects, taken after videofluoroscopy (VF)



O = outlier

Spirometry results for whole group by gender:

There was a difference when the FVC group was analysed by gender and aspiration. Within group male aspirators demonstrated a statistically significant difference using paired t-tests after swallowing in FVC compared with male non aspirators p=0.034.

When analysed by gender male aspirators using Mann-Whitney U tests demonstrated a statistically significant fall in FEV_1% after swallowing compared with male non aspirators p=0.001.

The same was seen with PEF in male aspirators compared with male non aspirators p=.018 and with MEF_{25-75} p=.005. As stated previously due to the small size of the sample this work can only be used as an indication for directions for future studies.

3.05.00 The spirometry results for the stroke group.

The spirometry data for the stroke subjects were analysed separately (34 aspirators, 16 non aspirators). Aspirating stroke subjects showed an improvement in FVC compared with non aspirating stroke subjects who showed a slight decline but this was not shown to be statistically significant (see tables 03.05.01, F-04 and F-05).

Aspirating stroke subjects demonstrated a greater fall from baseline post swallowing in FEV_1 than non aspirating subjects but again this was not statistically significant (see table 03.05.01, F-04 and F-05).

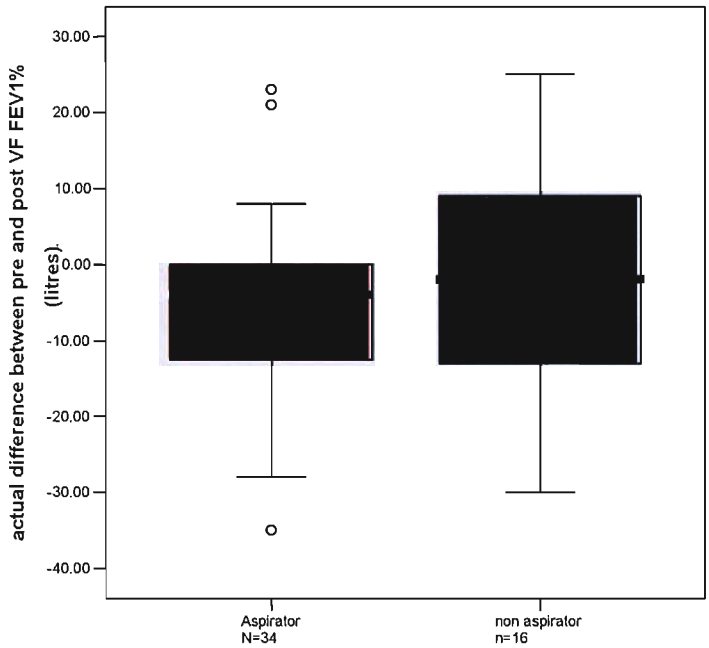
Aspirating stroke subjects however demonstrated a larger fall in FEV_1% after swallowing than non aspirating subjects and this was found to be statistically significant p=.005 (see figure 3.03.01 and table F-06). This pattern was also seen in PEF aspirating stroke subjects had a larger fall from baseline after swallowing than non aspirating subjects p=.016 again with male aspirating subjects demonstrating a larger fall than non aspirating subjects p=.030 (see figure 3.05.02). The MEF_{25-75} further mimicked the pattern p=.004 (see tables 03.05.01 and F-06).

This was also seen when analysed by gender with male aspirating subjects demonstrating a larger fall in FEV_1% than non aspirating p=.004, PEF p=.030 and .MEF_{25-75} p=.009.

Table 3.05.01 % achieved of % predicted spirometry measurements taken from stroke group

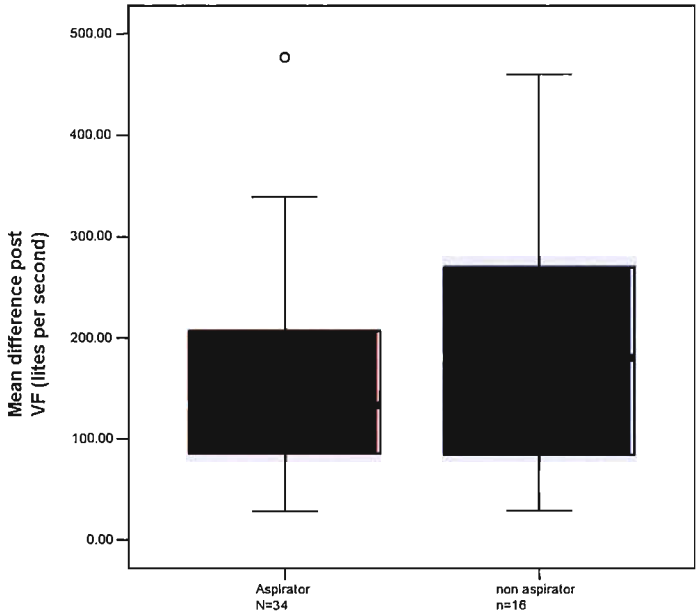
Spirometry Measurement	Time of measurement	Aspirators N=34	Non aspirators N=16
FVC (l)	Pre videofluoroscopy	72.90	73.72
	Post videofluoroscopy	76.47	72.79
	Difference (SD)	2.29	-1.39
FEV_1 (l)	Pre videofluoroscopy	65.48	60.83
	Post videofluoroscopy	63.84	57.39
	Difference (SD)	-1.74	-3.44
FEV_1%	Pre videofluoroscopy	95.87	86.11
	Post videofluoroscopy	87.81	82.72
	Difference (SD)	-7.94	-3.22
PEF (ls)	Pre videofluoroscopy	43.23	43.33
	Post videofluoroscopy	37.38	44.39
	Difference (SD)	-7.03	.78
MEF_{25-75} (ls)	Pre videofluoroscopy	50.26	39.72
	Post videofluoroscopy	41.94	36.28
	Difference (SD)	-8.26	-4.33

Figure 3.05.01: Box and whisker plots demonstrating median and interquartile ranges for mean difference in FEV_1% after videofluoroscopy in stroke group for aspirating and non aspirating subjects



O = outlier

Figure 3.05.02: Box and whisker plot demonstrating median and interquartile ranges differences for PEF after videofluoroscopy in stroke group for aspirating and non aspirating subjects



O = outlier

3.06.00: Spirometry results for the neurology group.

Spirometry data from the neurological subjects were then analysed separately (7 aspirators, 11 non aspirators). There were no statistically significant differences between the spirometry results of the aspirating and non aspirating subjects (see tables F-07-F-09). This may be due to the small size of the study group.

Table 3.06.01 % achieved of % predicted spirometry measurements taken from the neurology group

Spirometry Measurement	Time of measurement	Aspirators N=7	Non aspirators N=11
FVC (l)	Pre videofluoroscopy	65.67	83.25
	Post videofluoroscopy	68.00	85.42
	Difference (SD)	-1.83	2.17
FEV_1 (l)	Pre videofluoroscopy	41.67	80.25
	Post videofluoroscopy	38.14	82.25
	Difference (SD)	-3.83	2.00
FEV_1%	Pre videofluoroscopy	73.50	98.00
	Post videofluoroscopy	70.43	97.58
	Difference (SD)	1.33	-.42
PEF (ls)	Pre videofluoroscopy	24.67	56.83
	Post videofluoroscopy	20.86	53.92
	Difference (SD)	-3.00	-2.08
MEF_{25-75} (ls)	Pre videofluoroscopy	30.83	67.33
	Post videofluoroscopy	23.29	68.92
	Difference (SD)	-7.67	.92

3.07.00: Other parameters collected:

The researcher had planned to record MIP and MEP assessments before and after videofluoroscopy. This was tried with the first 20 subjects who consented for the trial. Unfortunately only one of the participants completed the full battery and was complaining of extreme fatigue afterwards (so much that his videofluoroscopy was delayed by 2 hours). All of the participants expressed dislike of the mouthpiece used to record the data and a number expressed concern that they were "unable to breathe". It was decided at this point to remove MIP and MEP testing from the assessment battery.

Table 3.07.01: Other information collected during assessment

		Aspirator N=43	Non aspirator N=33
Collar size	**Below 16/17"**	35 (46%)	16 (21%)
	16/17" or above	8 (11%)	17 (22%)
Smoking history	**Never smoked**	9 (12%)	13 (17%)
	Given up smoking	32 (42%)	13 (17%)
	Current smoker	2 (3%)	7 (9%)
Cough to command	**Yes**	40 (52%)	31 (41%)
	No	3(4%)	2 (3%)
Spontaneous cough	**Yes**	8 (10%)	27 (36%)
	No	35 (46%)	6 (8%)
Snoring history	**Never / occasional**	19 (25%)	20 (26%)
	Snorer / don't know	24 (32%)	13(17%)

3.08.00: Chi-Square Results comparing videofluoroscopy and other data collected

Results from the Chi-square analysis demonstrate a statistically significant relationship between collar size and aspiration in the whole group p = .002. Subjects with a small neck size were more likely to aspirate than those with a large neck.

When the whole group was subdivided by gender, male subjects who were non smokers or who had given up were shown to be more likely to aspirate than current male smokers p=.005. Male subjects with small necks were more likely to aspirate than male subjects with large necks (p=.003).

Chi-square analysis was then used to assess the relationship between aspiration and other data collected within the stroke and neurological group. Within the stroke subjects snorers were more likely to aspirate than non snorers (p= .042). Subjects with small necks were also more likely to aspirate than stroke subjects with large necks (p= .022).

There were no statistically significant correlations within the neurological group with the other parameters collected.

The stroke and neurology group were also analysed by gender. Within the stroke group male subjects who had never or given smoking were more likely to aspirate than male smokers (p= .023). Male stroke subjects who had a small neck were also more likely to aspirate than male stroke subjects who had a large neck (p=.032). There were no statistically significant correlations within the female stroke subjects or the male or female neurological group.

3.09.00: The results of the multiple logistic regression:

A multiple logistic regression (stepwise likelihood ratio) was undertaken to investigate causal relationships between binary variables for the whole group allowing for confounding variables. It also acted as a discriminant analysis to develop prognostic indicators .Smoking, collar size, snoring, spontaneous cough and voluntary cough, 2% drop of oxygen saturation, gender and disorder were all entered into the regression (table F-28).

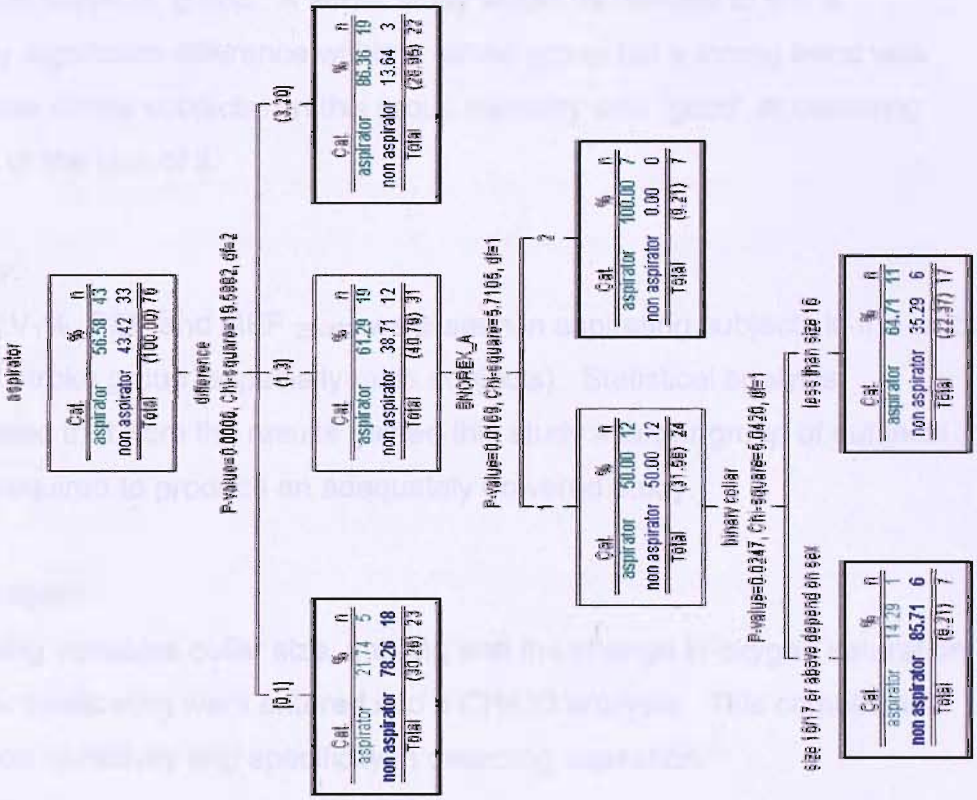
A relationship between a small collar size p=.006, snoring p= .051 and a fall in SO_2 of 2% or more from baseline p=.000 together were all found to significantly increase the risk of aspiration. Despite a logistic regression producing statistically significant p values the predictive value was still only 56%. It was thought this may be due to the interactions between the predictive variables.

For this reason a Chi-square Automatic Interaction Detector (CHAID) analysis was undertaken. CHAID is based on a combination of Chi Square and likelihood ratio and has also been called a sequence fitting algorithm. CHAID was used to study the relationships between the fall in oxygen saturation levels and a series of possible predictor variables. The CHAID diagram which was produced should be thought of as a "tree trunk" with progressive splits into smaller and smaller "branches". The initial "tree trunk" is all the participants in the study. A series of predictor variables (gender, smoking, snoring, collar size) were assessed to see if splitting the sample based on these predictors lead to a statistically significant discrimination in the dependent measure. The result at the end of the process means that the groups are maximally different from one another on the dependent variable.

3.10.00: CHAID analysis

The results of the CHAID analysis can be found in table 3.10.01. The CHAID analysis found that 78% of subjects who had a fall in oxygen saturation of 1% or less were non aspirators, and 83% of subjects who desaturated 3% or more were aspirators. The subjects who aspirated between 1% and 3% were further analysed by snoring. If these subjects were snorers they were all aspirators (100%). If they were not snorers the analysis continued by adding collar size. 85% of subjects with a large neck who were not snorers were non aspirators. 35% of those non snorers with small necks were non aspirators. There were 14% of non snoring subjects with large necks who were non aspirators and 65% of those non snorers with small necks were aspirators. The CHAID analysis identifies that measurement of collar size, snoring status and oxygen saturation levels post VF allows the correct assignment of 61(80%) subjects overall correctly as aspirators (86%) or non aspirators (73%). This gives this CHAID analysis an 80% sensitivity and an 80% specificity (see section 2.12) of detecting aspiration status.

Table 3.10.01 CHAID analysis using oxygen saturation change, snoring and collar size as predictive indices



3.10.00 Summary of the results:

Pulse oximetry:

The study was appropriately powered to look for a 2% or more difference from oxygen baseline after swallowing as an indicator of dysphagia as shown by pulse oximetry. This study demonstrated that oximetry was "moderately good" at detecting aspiration or the lack of it within a mixed group of subjects and in the neurological subjects' group. A larger study would be needed to find a statistically significant difference within a stroke group but a strong trend was seen in male stroke subjects. In this group oximetry was "good" at detecting aspiration or the lack of it.

Spirometry:

Falls in FEV_1%, PEF and MEF_{25-75} were seen in aspirating subjects in the whole group and stroke group (especially male subjects). Statistical analysis demonstrated that from the results gained this study a larger group of subjects would be required to produce an adequately powered study.

CHAID analysis:

The following variables collar size, snoring and the change in oxygen saturation levels after swallowing were entered into a CHAID analysis. This combination gave a good sensitivity and specificity in detecting aspiration.

4.00 CHAPTER 4: Discussion Study 1

4.01 Introduction:

Dysphagia is a very common pathology in the United Kingdom associated with many neurological conditions and, with an ageing population, its incidence, is likely to increase. There is a high cost associated with dysphagia both in financial and human terms. Acquired dysphagia requires accurate assessment with the minimum amount of risk and distress.

The objectives of this pilot project were to investigate the feasibility of using pulse oximetry and spirometry to detect aspiration in dysphagic patients and thereby provide clinicians with a reliable bedside assessment. To achieve these objectives additional factors such as snoring, smoking and collar size were also examined to build a predictive model for aspiration and compared to videofluoroscopy, currently considered by professionals to be the 'gold standard' in detecting aspiration.

Pulse oximetry measurements were recorded pre, peri and post videofluoroscopy. The results of the trial have demonstrated that a fall in oxygen saturation of 2% or more from baseline in the whole study group detected aspiration with 88.4% sensitivity and 54.5% specificity. The results also showed that the relationship between aspiration and collar size, snoring and a fall in oxygen saturation levels could be used to predict aspiration with an 80% sensitivity and 80% specificity.

The study found that there was no statistically significant difference in baseline oxygen saturation levels between aspirating and non aspirating subjects as a whole group (98.09%, 97.58%) or as the two sub-groups stroke and other neurology. These findings concur with Zaidi's study (1995) who found no differences between stroke subjects and matched hospitalized patients, but not with the investigator's previous study. The baseline oxygen saturation level was higher than Hirst's "normal elderly" of 95%. Non aspirating subjects were on average younger than the aspirating subjects. This concurs with Roquer's study (2003). This study's sensitivity and

specificity was higher than Wang et al (2005) although the method was similar. One reason for this is likely to be the previously discussed flaw, of using barium as a thickening agent, in that study. It also may be due to the fact that this study allowed subjects to aspirate more barium than Wang's study and therefore possibly causing greater bronchoconstriction. Any aspiration event is likely to result in some reflex bronchoconstriction. Methods for detecting such change in airway calibre include spirometry. FEV_1 is well documented for use in detecting acute changes in airway calibre during bronchial challenges. However it is uncertain how sensitive spirometry measurements are in detecting small changes in airway size, such as might occur during aspiration and this may account for why no statistically significant differences were found during this study.

Although this study was not adequately powered to find a statistically significant difference in spirometry measurements between aspirating and non aspirating subjects, it was found that aspirating subjects had consistently lower baseline spirometry levels of FVC, FEV_1, FEV_1%, PEF and MEF_{25-75} prior to videofluoroscopy assessment than non aspirating subjects. This was seen as a whole group, by gender or as subgroups, however this was not statistically significant. This trend may be because these subjects are 'more unwell' and compromised due to their dysphagia or it may be that repeated aspiration has a detrimental effect on the airways, e.g. the effect of food in the airways leads to sensitisation of the bronchial tissue which in turn leads to chronic bronchoconstriction.

It could be argued that changes in spirometry measurements in aspirating subjects may be partially due to a fatigue effect. Aspirating subjects may be generally weaker than aspirators and this weakness could have been exacerbated by repeated spirometry trials and led to falls in spirometry measurements after swallowing. Studies show that people who aspirate spend more time in rehabilitation than those who do not, have a poorer score on rehabilitation measures on discharge and are more prone to chest infections (Barer 1989, Yap & Chua 2002, Lee & James 2005). It was also a consistent trend in non aspirators that there is no statistically significant

change in spirometry measurements between before and after swallowing. Aspirating men had greater falls in FEV_1%, PEF and MEF_{25-75} than aspirating women. Smith et al (1999) found that men were more likely to aspirate than women and previous studies have suggested that women have a more sensitive cough reflex than men (Prudon et al 2005, Fujimura et al 1996). The spirometry results from this study may imply that male aspirators also have a greater respiratory response to their aspiration even than female aspirators.

Bronchospasm is known to produce a reaction in PEF and MEF_{25-75} which has been the mechanism suspected of causing a fall in arterial oxygen saturation in aspiration. The fact that there is no change in either of these measurements in non aspirating subjects but a falling trend in aspirating subjects would support the theoretical model of bronchoconstriction during aspiration. The fact that there was a change was FEV_1 but that was not statistically significant, may relate to the delay in taking spirometry measurements post aspiration / swallow or may reflect that the study was not powered sufficiently to detect this change. Based on this finding increasing the number of subjects in the study may adequately power it to find a statistically significant difference but probably not a clinically significant difference that could be used in a bedside assessment. The forced expiratory ratio FEV_1% was consistently statistically significantly lower in aspirating compared with non aspirating subjects. This would lend further weight to the theory of an obstructive pattern and fit the bronchoconstriction hypothesis. However FEV_1% is known to be less reliable than FEV_1.

In this study subjects who aspirated had significantly reduced PEF. Smith Hammond et al (2001) studied peak cough flow (measuring airflow and sound), comparing severe dysphagics (as measured by either nasendoscopy or videofluoroscopy) with others. Smith Hammond et al (2001) found that peak cough flow had high sensitivity in detecting non dysphagics. Peak cough was not recorded in this study and the relationship between peak expiratory flow and peak cough flow in dysphagic patients is uncertain.

This study may be criticised for recording spontaneous cough as "reported heard" or "heard on videofluoroscopy" All other studies looking at spontaneous cough sensitivity (there are none published relating to dysphagia) have used a nebulised agent such as capsaicin which provides more objective information (Fujimura et al 1996). There have been no published studies comparing clinicians "listening" abilities for judging cough effectiveness. Yet clinicians anecdotally report that they can describe an "effective or not effective" cough. Spontaneous cough responsiveness has been reported to be enhanced with dysphagia (Smith 1989) Wong (1999) reported that patients with chronic obstructive pulmonary disease have a lower cough threshold than controls. Addington (1999) found that assessing spontaneous cough reliably predicted (100% specificity) the development of pneumonia but this was not correlated against the presence of dysphagia. Lack of spontaneous cough in this study was clearly a strong indicator of aspiration but the presence of a voluntary cough was not a protective reflex against aspiration. The results from this study concur with the findings of (Smith & Wiles 1998). They may also correlate with Smith (1999) who found men were more likely to aspirate silently than women, a finding also made in this study. Future research could look for a relationship between sensitivity to cough challenge and silent aspiration.

However Newham (1997) found that spontaneous cough sensitivity decreased with age and the results from this study concurs with this. Smith (1998) agreed with this but also found that the youngest adults in her study were more likely to silently aspirate. This was not found by this study where a greater number of older patients silently aspirating. It may have been a bias in the study that there were significantly higher numbers of silent aspirators than suggested in the literature in this study. This may be due to the fact that the data were collected from a clinical environment to which patients were sent to confirm or refute the suspicion that they were silent aspirators.

Smith Hammond (2001) however, found that voluntary cough measurement compared with controls in stroke was altered and that there were significant differences between severe aspirators as compared to non-aspirators when

looking at the peak expulsive phase of peak flow. This study did not look at peak flow in such detail but some statistically significant differences were found in the peak flow of aspirators compared with non aspirators.

Snoring history was recorded to investigate the link between snoring and aspiration. The recording of snoring can be criticised as it was a subjective measure from either the subject or their family. The investigator noted that female subjects were often reluctant to discuss snoring as it was considered 'un-ladylike' and this may have resulted in under-reporting. Also some subjects who lived on their own reported that they did not know if they snored which again may have led to underreporting. Previous studies have found lesions in the muscles of the uvulas in people who have snored for a long time (Series et al 1995). There have also been changes in swallowing patterns found in those who snore (Jaghagen et al 2000) thought to be linked to changes in pharyngeal sensitivity and neurological changes. Snoring was found to be statistically significantly associated with aspiration within the stroke group of this study and there were trends found within the neurology group. Snoring was also found to be the second most useful factor to predict aspiration in the CHAID analysis. It is not clear from this study if snoring was a predictor pre stroke to those people who would aspirate, if the presence of aspiration and or stroke caused these people to snore, or if there is simply an association between snoring and aspiration with no causal link.

Collar size was recorded to look for correlations between aspiration and large necks. The rationale being that subjects who have a size 16 ½ / 17 (depending on sex) or above neck size are more at risk of sleep apnoea due to, amongst other variables, changes in tone. Following a neurological event muscle tone is frequently affected and as such it was hypothesised that low tone in the pharynx would make the subject more likely to aspirate by causing reduced pharyngeal constrictor activity and reduced hyoid elevation and excursion. Collar size of aspirating and non aspirating subjects was found to be highly predictive of aspiration. It was expected that subjects who had a large neck may be more susceptible to swallowing difficulties due to an obstructive type pattern such as that seen in obstructive sleep apnoea,

however it was subjects with a small neck size who were more likely to aspirate. This appears to be a counter intuitive finding. This may be due an abnormal distribution of neck size within the population with fewer people having large neck sizes. This may mean that the group was not representative, or it could simply be a chance finding

Smoking history was recorded to look for a relationship between smoking frequency and aspiration. The rationale being that smoking reduces the pharyngeal sensation and is known to cause a reduction lung function. The differences in the whole group between aspirators and non aspirators were not statistically significant but there was a trend seen. There was a statistically significant difference between in the whole group between aspirators and non aspirators in men. When analysed by gender and disorder there is a chi square correlation between male stroke subjects who smoke and aspiration p=.023. Research has already demonstrated that smoking puts men at a higher risk of stroke than women (Roquer 2003). This study would suggest that it also puts them at a higher risk of aspiration. This study relied on the subjective history given by the patient and was therefore vulnerable to bias as smoking is no longer socially acceptable by a large number of the public, so there may have been an underreporting of "current" smoking. Also the data may have been biased as smoking was very common in the past and so "previous smoker" may be over represented and infact the correlation between smoking and aspiration may be under-represented.

The subjects from the study have been analysed for the purpose of this thesis as a whole group and then as two sub-groups, stroke and mixed neurology. The patient group chosen for this study were patients with one of the following conditions, acute stroke, sub-acute stroke, Parkinson's disease, multiple sclerosis, head injury, Huntington's chorea and motor neurone disease; all characterised by a perceived difficulty in swallowing as assessed by a Specialist Speech & Language Therapist or Staff Grade E.N.T. Surgeon. The diagnosis of stroke was made by a consultant stroke physician using a CT scan. There may have been unseen pathology being included in the study. The patient group studied was limited in numbers by the time restrictions for

recruitment. However, the study design was suitable for use with the numbers gained and was powered to detect a 2% fall from baseline oxygen saturation levels. The results have shown some agreement between two objective assessment tools which need to be further tested with a larger study.

The subjects recruited for the study were consecutive referrals for the videofluoroscopy services. The average age of the aspirating patients was 75 years compared with 67 years for non aspirating subjects. There are no obvious reasons within the study why there should be such a large disparity between the ages of the two groups, except that stroke is more likely in old age and the resulting disability more severe. The results were similar to the results found by the researcher in her previous study (Collins & Bakheit 1997). The female subjects were on average 3 years older than the male subjects in the aspirating group and an average 12 years older than the non-aspirating groups. These results are similar to Roquer's study (2003) who found in stroke that women were likely to be older than men when they had their first stroke and were more likely to be dysphagic.

This study may be criticized for recruiting what could be considered an atypical group of subjects. All subjects in the study had already been referred for videofluoroscopy because they were suspected of aspiration. A wider sample from the general patient population may be needed to confirm these results. However current radiation protection guidelines in the UK prevent researchers using subjects who do not have a recognised swallowing disorder undergoing videofluoroscopy due to the radiation doses involved.

Methodology

Videofluoroscopy was the objective method of assessing dysphagia of choice for this study because it is considered the 'gold standard' in detecting aspiration. The videofluoroscopy studies took place in busy NHS clinics. This study may be criticised for using two positions during videofluoroscopy instead of standardising the subjects into either a sitting or standing position. However both positions reduce the effects of hypoventilation and pulmonary

shunting (Walshaw, 1984) and promote maximal chest wall movement (Elizabeth, 1993). It was difficult within a clinical setting, as this study was based, to standardise the patients into a sitting or standing position. This was because not all patients had adequate standing balance therefore some had to be sat down. However the sitting position does not allow the radiologist to follow the path of the barium down the oesophagus and into the stomach. It is unlikely that this will have influenced the results however and both positions are used interchangeably in clinical assessment.

There is no consensus regarding standardisation of a videofluoroscopy protocol. In research facilities there may be rigid protocols set up for individual studies but this is not usual in a clinical NHS setting. The study was limited in judging the size of the bolus because there was no protocol developed in either centre to regulate the amount of barium impregnated food or fluid the patient ingested. This reflects standard NHS practice. The study could have been improved if each subject had been given the same prescribed amount of food and fluid. Some of the trial swallows are from a 5 ml spoon however differences between patients arise when the subjects are asked to drink from a cup. The average size mouthful is 20 ml but this is impossible to measure reliably so a best estimate is required. The study could have benefited from computerised pixel counting which allows the accurate measurement of the size of the bolus either swallowed or more importantly aspirated. This may have then assisted in assessing how much aspirate is needed to cause bronchoconstriction but this was not available to this study and currently there are no published papers in press using this technique.

Each subject was also screened in a slightly different way when looking for evidence of aspiration. Although all subjects were filmed in anterior posterior. and lateral positions with different food and fluid consistencies there was no absolute method about screening times. This may have meant that potentially aspiration events post swallow may not have been witnessed and falls in oxygen saturation levels recorded in 'non aspirators' may have actually been misdiagnosed aspiration events.

Studies have been conducted to compare invasive arterial blood gas analysis to pulse oximetry and found them to be comparable (Wurternberger 1994) Limitations and inaccuracies of pulse oximetry have been extensively reviewed (Stoneham, 1995, Nyarwaya, 1994). An important limitation highlighted by Severinghaus (1987) demonstrated a potential time delay between the onset of any hypoxic event and its detection by a pulse oximeter. This can also vary depending on where the oximeter probe is sited (Lawson, 1987). All the probes were sited in the same place in this study but the time delay as discussed in Nyarwaya's (1994) and Severinghaus (1987) papers may have led to aspiration not being detected during the assessment time. Pulse oximetry is not currently used within routine clinical Speech & Language Therapy bedside assessment. As well as the authors previous study which demonstrated a high level of sensitivity and specificity in detecting aspiration, previous studies (Smith, 2000, Sherman, 1999, Brown, 1983, Zaidi, 1995, Rogers, 1993) have also all demonstrated a positive agreement between aspiration and desaturation.

A finger probe was used for this study to record the waveforms. This type of probe was used because it is the most easily available within the hospital environment. It has been suggested that movement artefact can reduce the efficiency of the probe. To try and combat this, in this study, the probe was placed on the affected or non dominant hand. However it is acknowledged that eating is an activity that requires movement and often if the subject was standing they may have used their affected arm to maintain balance, and so there may be the influence of movement artefact within this data. Patients who were on continuous oxygen to maintain their oxygen levels had not been excluded from the study, but their results have not been included in the cohort as they needed to remove their face masks to eat which some times caused the oxygen levels to drop. This is a group of patients who are considered very vulnerable to aspiration, by Speech & Language Therapists, due to a poor level of co-ordination between swallowing and breathing. During the preparation for videofluoroscopy it became obvious that they were unable to

maintain their oxygen saturation levels even while waiting for the examination to begin and so none of this data were included in the analysis.

Spirometry is cheap, reproducible and easy to undertake in a variety of locations by members of the multi-disciplinary team. Spirometry is not routinely used in the assessment of dysphagia by Speech & Language Therapists. One team has published spirometry findings in relation to swallowing (Hirst et al 2002), but they only took baseline spirometry readings and pulse oximetry levels prior to swallowing assessment and not afterwards.

A portable, handheld flow spirometer, with disposable cardboard mouthpieces was used for the study to record the respiratory information. This type of spirometer was used because it could be brought to the videofluoroscopy suite. It has the limitation of not being a laboratory based volume spirometer, which allows the patient to breathe normally through the equipment before taking any measurements, but this type of spirometer has been used extensively in clinical trials. A minimum of 3 tests were taken pre and post videofluoroscopy to try and ensure a good technique. Patients who had severe oral- motor dyspraxia (n=2) did have difficulties undertaking the technique to produce reliable results and as such could not complete all of the assessments. Patients who simply had a facial weakness were assisted in producing a seal around the mouthpiece as suggested by Fiz et al (1993). Under these circumstances it is uncertain how accurate the spirometry data in this study are, and therefore results must be interpreted with some caution.

MIP and MEP measurements are routinely used in respiratory assessment clinics and were therefore included in the protocol for this study to measure respiratory function. It was not anticipated that patients would be unable to complete the assessments and then undertake a videofluoroscopy, due to the physical exertion required. As this had been a problem for the first 20 subjects, MIP and MEP were removed from the assessment battery. It was concluded that this was not a suitable routine assessment for the dysphagic patients. In support of this there are no data for this subject group included in

this thesis. With hindsight this problem could have been avoided with appropriate pilot work.

This study design could be criticised for the following reasons, there was poor subject matching for age between the aspirating and non aspirating groups. A 2% or more drop in arterial oxygen saturation was used to indicate aspiration. However there is generally considered to be a +/- 2% error rate in these measures. This figure was chosen because other studies, including the author's previous work have demonstrated that 2% or more drop was able to detect aspiration. The low specificity found does suggest that many people who do not aspirate will show a 2% change in oxygen saturation. Choosing a higher percentage e.g. 3% (which is what the CHAID analysis chose) would increase the specificity in detecting aspiration, but with an associated reduction in sensitivity. The amount of barium within the food and the amount of food given to each subject during VF was not standardised. One may argue that a standardised amount such as 3 oz (used in water testing) should have been given. Varieties in quantities may have resulted in more of the substance being aspirated in some subjects and therefore potentially a larger fall in oxygen saturation from baseline. Unfortunately this was a clinical assessment undertaken for clinical reasons to diagnose dysphagia and the dose of barium given was not under the control of the researcher.

Measurements of oxygen saturation were taken continuously from the start of the examination through the point of swallow / aspiration to the end of the investigation. This was because it has been demonstrated that in neurologically impaired subjects the inspiratory phase post swallow is more likely to produce a mist aspiration (Selley, 1989), and more likely to draw any aspirated food or fluid further into the lungs. By continually recording oxygen levels it increased the probability that any desaturation would be detected. However, by only using the lowest level of oxygen saturation level recorded, there is the risk that these figures represent a temporary anomaly. Ideally an indwelling arterial catheter would have been used to provide information regarding arterial blood gases. This would be hard to justify because it is an invasive procedure and would have no benefit to the research participant.

Spirometry results were taken as soon as possible after the VF examination had finished, (no more than 5 minutes). The VF examination takes approximately 30 minutes, therefore the maximum time between aspiration and final spirometry reading would have been 35 minutes. This meant that any immediate response by the lungs or airways post aspiration may have been missed (Malmberg 1993). It was not, however, practical to interrupt an NHS clinical examination to take spirometry readings immediately after an aspiration event. Low FEV_1% may indicate the presence of airway obstruction. PEF reflects airway calibre, mainly of the bronchi and larger bronchioles, which are subject to reflex bronchoconstriction, especially in an obstructive pattern of lung disease. However PEF is dependent on expiratory effort and previously has been considered unsuitable for some debilitated patients. The MEF_{25-75} reflects changes in the smaller peripheral airways. It is not considered to be as reproducible as the FEV_1 it is derived from, and so is only used when other lung volumes are normal. In practice only values less than 65% of predicted volume are considered abnormal. This study was looking for trends in differences of lung response to aspiration. Coates (1993) has suggested that sometimes "when an immediate response to a lung challenge is expected the FEV_1 or PEF should be monitored. A delayed response can reduce the FEV_1 but this is not inevitable. This study found a response in FEV_1% and PEF and a trend in FEV_1 but it was not statistically significant so it would suggest that the second set of spirometry readings were nottaken close enough to the aspiration event.

Conclusion:

This study has demonstrated that while pulse oximetry and spirometry show some differences between aspirating and non aspirating subjects neither spirometry or pulse oximetry are accurate or robust enough to be used as indices to independently detect aspiration. Snoring history, smoking and collar size are poor independent predictors of aspiration. A combination of prediction using snoring history and collar size and detection using oxygen saturation levels improves the sensitivity and specificity of assessing dysphagia. Spirometry measurements of PEF, MEF_{25-75} and FEV_1% can be

taken. A fall in either may indicate the presence of aspiration but this is not definitive in diagnosis, due to the reasons previously stated in the thesis. If spirometry is used readings should be taken as quickly as possible once bedside assessment has finished. To maximise the chances of detecting aspiration the subject should have pulse oximetry measurements taken continuously when eating. Subjects who then demonstrate a fall in oxygen saturation levels after swallowing who snore and have a small collar size should be considered to be at a greater risk of aspiration.

In conclusion the main result of this study is that neither pulse oximetry, nor spirometry are consistently reliable indicators of aspiration in dysphagic patients when used on their own or in combination with each other. The CHAID analysis, however, shows that if continuous pulse oximetry, recorded when eating or drinking, is combined with the presence or absence of reported snoring and a measurement of collar size a high sensitivity and specificity for the detection or exclusion of aspiration can be achieved even with a reduced sample size.

5.00 CHAPTER 5 Introduction Study 2:

The first study showed that subjects who snored and exhibited a drop in oxygen saturation levels were more likely to aspirate than those who did not snore or drop their oxygen saturation levels when eating. A second study was designed to explore the relationship between sleep, aspiration and oxygen saturation levels by recording the patterns of nocturnal oxygen saturation of aspirating and non aspirating subjects during sleep. The study also aimed to further analyse any differences found within these patterns and to propose possible causes for these findings. The investigator chose to study subjects who had sustained a stroke 6 weeks or more prior to the study.

It was therefore necessary to review the literature related to normal sleep patterns, sleep patterns post stroke and relationship between sleeping and swallowing. Finally the question of concurrent pathology which may cause additional changes within a person's sleep pattern will be explored, leading to the hypothesis for this study.

5.01 Normal sleep patterns:

The literature relating to sleep is extensive. For the purpose of this review the author has focused primarily on physiological changes relating directly to the upper airway, and the respiratory cycle. During sleep a number of physiological changes temporarily occur. There is a reduction in the activity of the upper airway dilator muscles including the pharyngeal constrictors and the genioglossus. This results in a decrease in airway size and an increase in upper airway resistance. During sleep, airway narrowing may occur in an anteroposterior (AP) direction as a result of thickening or posterior movement of the soft palate and tongue. Alternatively lateral collapse of the airway may occur as a result of thickening of the lateral pharyngeal walls.

Trudo et al (1998) studied normal subjects during sleep and when awake with MRI in order to characterise the upper airway and soft tissues. They found

that changes in lateral wall thickness, tongue oblique distance and soft palate position and width significantly contributed to dependant retropharyngeal (RP) narrowing during sleep. All of the subjects following a period of sleep deprivation had changes in the upper airway and surrounding soft tissues during sleep so that the volume of the RP airway was reduced by 19%. In contrast they found that the retrogenioglossal (RG) area was unchanged during sleep. Measurements of the tongue area and position did not significantly change during sleep. The team summarise their findings by suggesting that there are larger changes during sleep in the RP than RG area because of changes in the soft palate position and /or lateral pharyngeal wall thickening during all sleep due to reduction in muscular activity.

Contractions and involvement of the rib cage and diaphragm vary depending on the type of sleep stage the person is in. During Non Rapid Eye Movement (NREM) sleep the rib cage contributes more to the respiratory pattern than when awake but during Rapid Eye Movement (REM) sleep the rib cage component is reduced or even absent. There is paradoxical retraction of the intercostal spaces during inspiration. Coincidentally the tone of the diaphragm is reduced. This causes a reduction in the functional residual capacity. The reduction can result in closure of the small airways which persists during inspiration and thus may contribute to hypoxemia. Closure is especially likely to occur in older people and people with diseases which affect the small airways. In a study of 350 healthy subjects mean oxygen saturation levels during sleep were 96.5% (+/- 1.5%) which decreased slightly as subjects aged (95.1%) (Gries & Brooks 1996).

Sleep shifts the carbon dioxide response curve slightly to the right because during sleep the ventilation and tidal volume become reduced and these reductions fail to match the rate of metabolism by approximately 10%. The arterial PCO_2 normally increases during slow wave sleep, rising as much as 5 to 6 torr during deep sleep.

5.02 Sleep patterns associated with stroke

Changes in sleep patterns are common in stroke. Numerous studies have tried to find an association between stroke and subjects with sleep disordered breathing, believing that this may be a possible cause or at least a contributing factor in stroke (Partinen 1985, Koskenvuo 1987, Dyken 1996). Somers et al (1993) linked the changes in muscle tone found in REM sleep with sympathetic nervous system changes and proposed that this could be an important step in understanding what triggers ischaemic strokes in patients with vascular disease. There have been conflicting views submitted regarding cerebral blood flow in patients with sleep apnoea. Hajak and team (1996) compared control patients with patients with sleep apnoea and found that at various stages of sleep the obstructive sleep apnoea syndrome (OSAS) patients had a differing pattern of blood flow from the controls. Klingelhofer (1992) found increased blood flow during sleep apnoea periods to the cerebral cortex in patients with OSAS. Netzer et al (Netzer 1998) observed 12 patients from a sleep centre for snoring, sleep patterns and breathing and correlated this information with the subjects MCA blood flow. They compared periods of obstructive apnoea, obstructive hypopnoea, and central apnoeas. Their results showed MCA blood flow declined during a significant number of the obstructive hypopnoea and obstructive apnoea periods compared with the times the subjects had central apnoea. Szucs (2002) found a difference in sleep apnoea frequency between ischaemic and haemorrhagic stroke. She further reported that sleep apnoea was a transitory symptom of haemorrhagic stroke.

Multiple studies have described disordered breathing syndromes following a stroke and there has been some attempt to find an association between site of lesion and the type of breathing pattern likely to be found (Plum 1970, Heyman 1958, Lee 1976, North 1974, Deveraux 1973). Many of these studies suggested a high prevalence of sleep disordered breathing in stroke patients. Bassetti (1997) studied patients with an acute first stroke (ischaemic) during waking and sleeping to assess their breathing. They found that 54% of

the subjects had classical OSAS but that many more had other disorders of breathing. Parra et al (2000) studied stroke patients during the acute and sub acute phases of recovery. The team did not find an association between frequency and type of sleep disordered breathing and place of neurological insult but they did find that in both the acute phase 71% and in the sub-acute phase 61% had some degree of sleep disordered breathing. Sandberg et al (2001) studied 133 subjects in the acute and sub-acute phase of recovery post stroke and again found no association between the type or location of the stroke and sleep apnoea. They found 59% of subjects fulfilled the criteria for sleep apnoea but it should be noted that a number of patients were on medication which provided a sedative effect. Harbison et al (2002) studied 68 mainly older subjects in the acute and sub-acute phase of recovery from stroke. In the acute phase of stroke they recorded 96% of subjects with some degree of disordered breathing during sleep and 74 % in the sub-acute phase. Harbison proposed that patients with lacunar strokes compared with cortical strokes and older patients were more likely to suffer from sleep disordered breathing but the subject groups were larger in both of these groups.

Roffe (2003) compared 100 acute stroke patients with community controls level of nocturnal oxygen saturation. She found 32% of stroke patients had a mean nocturnal saturation of <93% and 6% had a mean nocturnal saturation of <90% compared with 94.5% of the controls. She also found no consistent pattern between place of stroke and lower oximetry readings but found that the lowest readings were from patients with total anterior circulating strokes and the highest were from lacunar strokes.

Turkington et al (2002) studied sleep disordered breathing after stroke. They looked for predictors of upper airway obstruction and assessed cough, gag, a water swallow test, Glasgow Coma Scale, sex, age and neck circumference and used a sleep system analysis. They found that neck circumference and BMI were predictors of the development of upper airway obstruction.

One study has also reported that sleep disordered breathing in stroke may also influence long term outcome. Good et al (1996) reported that sleep disordered breathing was associated with poor functional outcome.

There is high prevalence of sleep disordered breathing in people who have had a stroke both in the acute and sub-acute phase but it is not apparent if this is a cause or a sequelae of stroke. There is no apparent correlation however to the site of the stroke or the degree or severity of the breathing disorder. There does appear to be a relationship between neck circumference and BMI as predictors of upper airways obstruction. There may be evidence that sleep disordered breathing following a stroke will have an adverse effect on long term outcome.

5.03: Normal sleep patterns and swallowing:

The swallowing cycle is very well coordinated with the breathing patterns in healthy humans. It is a widely held belief that aspiration of upper airway secretions is a common occurrence in normal subjects during sleep. Infections are prevented by mucociliary clearance, cough or phagocytic activity. Infection would only arise when either the normal host's ability to cough is reduced, defence mechanisms are suppressed or that the volume of aspirated secretions increases.

There are only 3 studies currently that have examined nocturnal aspiration. Huxley (Huxley 1978) compared 10 patients in coma with 20 sleeping "normal" subjects. He injected a solution of an iodine isotope into the nose and looked for residue in lung parenchyma the following day. The authors found that 7 out of 10 of the coma patients aspirated and that 9 out of 20 of the "normal" subjects also aspirated. They concluded those "normals" that slept most soundly all aspirated, while the "restless" subjects did not.

Kikuchi (Kikuchi et al 1994) used a slightly different technique comparing 10 "normal" subjects with 14 patients who had previously been diagnosed with community acquired pneumonia. They found that only one of the healthy controls compared with 10 of the study subjects aspirated when checked by scanning following day.

Gleeson (Gleeson et al 1997) assessed 10 "normal" male volunteers using a different radioactive tracer, technetium, over a period of 2 nights. He found that 50% of his study group aspirated at some point over the 2 night study. He was unable to find any significant differences between those who did and those who did not aspirate.

Kelly et al (2003) found statistically significant differences in the coordination of breathing and swallowing when asleep and awake in young and elderly healthy subjects when measuring swallowing and airflow during bolus swallows and while awake. They have also found that there was greater variability in the swallow apnoea (SA) period than previous studies but there was even greater variability and significantly more occurrences of SA occurring during the expiratory-inspiratory cusp during sleep.

It may be concluded from these studies that nocturnal aspiration is a "normal" occurrence for some people but not all and that possibly the work undertaken by Kelly may indicate that it is the swallow apnoea period that leads to this variability.

5.04 Sleep patterns with abnormal swallowing

Some studies have tried to find a link between snoring and abnormal swallowing, the rationale being that both habitual snorers and OSAS patients have been shown to have neurogenic lesions in the palatopharyngeal muscle, which appear to develop as the condition worsens. Some authors have hypothesised that these lesions may also affect swallowing.

Teramoto and colleagues (Teramoto 1999) found that the swallowing reflex in patients with obstructive sleep apnoea was impaired. They demonstrated that using a swallowing test that they had devised, that there was a delay in swallowing with patients with OSAS as compared to controls and that patients with OSAS took an inspirational breath after swallowing more quickly than the controls. They investigated this further (Teramoto 2001) by examining the

relationship between swallowing function and nocturnal oxygen saturation levels. Swallowing was tested by a non standardised method devised by the authors and OSAS was confirmed by polysomnography. Twenty four subjects with OSAS and aged matched healthy controls were studied for two or more consecutive nights. An association was found between nocturnal oxygen saturation level and an impaired daytime swallowing reflex.

Jaghagen studied 41 patients who were not diagnosed with dysphagia but who were seeking treatment for heavy snoring and 15 healthy controls and assessed them with videofluoroscopy. She stated that snoring patients were 7 times more likely to have abnormal pharyngeal stage swallowing than the controls. She reported that pre-swallow loss to the pharynx and delays in the triggering of the swallow were the most common abnormalities followed by pharyngeal residue and laryngeal penetration (Jaghagen 2000). These would be common findings in patients with reduced pharyngeal sensation such as some stroke syndromes or M.S. She did not however give the age of the patients or the food substances used. This is important because older patients trigger swallows later than younger patients and thicker boluses are also triggered later in the swallow than thinner boluses. Teams who have studied people with multiple sclerosis believe that there is a triad of abnormalities related to abnormal swallowing: glossopharynolaryngeal paralysis, dysfunction of the respiratory nuclei of the medullary respiratory oblongata and decreased sensitivity of the respiratory centre to $C0_2$ which may cause nocturnal respiratory failure (Howard 1992, Popova 2000). Barthlen (2000) reported two ALS patients who were complaining of daytime sleepiness who both had bulbar symptoms which affected their swallowing.

Atypical neurogenic lesions have been found in both OSAS and habitual snorers, but the significance is unclear. Subjects with OSAS have been shown to have a decrease in nocturnal oxygen desaturation and delayed deglutition. The frequency of abnormal swallowing is significantly higher in subjects who seek treatment for snoring but who have no apparent neurological deficit. People with multiple sclerosis who have swallowing disorders also have changes to the respiratory nuclei within the medulla

oblongata and decreased sensitivity to hypercapnia, a mechanism which may be unique or may underlie other abnormal swallowing conditions.

5.05 Sleep Apnoea Syndrome:

The definition of apnoea is a cessation of airflow. If the cessation lasts longer than 10 seconds it is considered to be significant. Hypopnoea is defined as a reduction in airflow or respiratory effort for more than 10 seconds accompanied by an oxygen desaturation of 3% or more. Sleep apnoea is divided into central, obstructive or mixed. In central sleep apnoea there is no respiratory effort, where there is no airflow (in spite of activity of the respiratory muscles). Obstructive apnoea is characterised by respiratory effort without airflow, whilst central apnoea there is no respiratory effort. The first descriptions of OSAS appeared in 1966 (Gastaut 1966). Studies have shown that sleep apnoea is common. Between 2 and 4% of middle age adults (ratio of 2:1 male: female) have clinically significant periods of apnoea (Bearpark et al 1995, Stradling 1991, Young 1993). It is also more common in the elderly (Bixler 1998).

OSAS is usually characterised by obstructive or mixed apnoea, which is more common than central sleep apnoea. It has been suggested that a depressed response to carbon dioxide during sleep may be involved in the mechanism of central sleep apnoea. This lack of central respiratory drive is a potentially dangerous condition in both infants and adults. The waking state has an important stimulatory effect on ventilation.

Chemosensitivity is important for maintaining ventilation during sleep. This was demonstrated by observing patients with carotid body denervation who show an increase in sleep related hypoventilation. Sleep apnoeas or hypopnoeas may also be caused by an increase in PCO_2 as may occur during hypoxic hypoventilation. This subsequent reduction in ventilation may then cause hypoxic hypercapnia which then in turn leads to hyperventilation and consequently a cycle of hypoxia-induced periodic breathing. Studies have shown that there is a reduction of output from medullary respiratory neurones,

particularly during NREM sleep whereas in REM the output from these neurones tends to be related to the variability in breathing pattern. Raised carbon dioxide levels lead to hyperventilation, reduce the amount of REM sleep and prevent its occurrence. REM is associated with a depression of arousal responses to hypoxia and hypercapnia.

In obstructive sleep apnoea the central respiratory controller does issue the command to breathe, but the upper airway is obstructed. Several large studies have found OSAS in obese patients or patients with a very large neck, who were generally male with a strong history of cigarette smoking and alcohol consumption (Young et al 1993). In summary OSAS is common and of mixed aetiology. It is implicated in nocturnal hypoxia.

5.06 Physiological changes in obstructive sleep apnoea syndrome:

No single soft tissue structure has been identified as the cause of obstructive sleep apnoea syndrome but some studies identifying the tongue, soft palate and lateral pharyngeal muscles have been undertaken. Schwab compared patients with OSAS to controls, and found OSAS subjects had thicker pharyngeal walls compared with controls when they were awake (Schwab 1995). Mezanotte and team (Mezanotte 1992) assessed using electromyogram (EMG) genioglossal activity in awake patients with OSAS and controls, finding that the apnoeic patients have significantly greater basal genioglossal activity than compared with controls leading them to propose that during waking, increased pharyngeal dilator muscle activity in OSAS causes the patient to compensate for diminished airway size in order to maintain airway patency. Schellengberg and team (Schellengberg 1999) evaluated 420 patients attending a sleep disorder centre to try and find associations between anatomical abnormalities and OSAS. Controlling for neck circumference and BMI they found that lateral narrowing of the pharynx was the sole independent risk factor for men in developing OSAS there was no such association for women. There was weak association with tonsillar enlargement, uvular enlargement and tongue enlargement but not for low

lying palate, retrognathia and overjet so it is only possible to say that there are diffuse soft tissue changes present in subjects with OSAS.

5.07: Gastroesophageal reflux (GOR) during sleep:

There is a possible pathological link between OSAS, GOR, and chronic cough in young and adult patients. Valipour et al (2002) reported in their study that of the 271 subjects referred for sleep studies 73% of them complained of GOR related symptoms but that this did not influence the arterial oxygen saturation dips per hour. Gislason et al (2002) demonstrated that the occurrence of gastroesophageal reflux after bedtime was strongly associated with both asthma and respiratory symptoms as well as with symptoms of obstructive sleep apnoea syndrome but again no desaturation occurred during sleep.

5.08 Rationale for study:

Strokes are a common illness and are well known to cause disordered swallowing. Many of the patients who have disordered swallowing will aspirate. These patients will have a worse prognosis, both short and long term, compared with those who do not. It is therefore important to be able to identify this group. Although there have been many attempts to find a link between strokes, sleep apnoea, snoring and collar size these have not been entirely successful.

Previous studies undertaken by the author and others however, have shown a positive relationship between dysphagia and arterial oxygen desaturation in subjects who aspirate. There have been no studies observing oxygen saturation levels in subjects who have had a stroke lasting longer than 6 weeks and who have swallowing problems while sleeping. There have also not been any studies comparing the oxygen saturation of aspirating and non aspirating subjects when sleeping.

A review of the literature has demonstrated that aspiration may be due to damage between the central respiratory controller and the swallowing centres but it also may be due to, or exaggerated by, discrete changes in the upper airways due to snoring, smoking or sleep apnoea. Subjects with stroke may have disordered breathing patterns which lead to aspiration due to in coordination. During sleep many respiratory impairments are magnified. This study wished to investigate if there are differences in nocturnal oxygen saturation between aspirating and non aspirating stroke subjects during sleep.

5.09 Hypothesis:

The first study in this thesis demonstrated an association between disordered swallowing, aspiration and a fall in oxygen saturation levels during swallowing. This suggests that a fall in oxygen saturation levels during swallowing could be a sensitive but not specific indication of an aspiration event. Patients with disordered swallowing may also be at risk of silent aspiration while sleeping. It was therefore hypothesised that stroke patients with disordered swallowing may have episodes of silent aspiration during sleep. In view of the findings from the first study it was further hypothesised that these episodes of aspiration would be associated with periods of oxygen desaturation.

The underlying hypothesis to be tested is that subjects who aspirate following a stroke will have episodes of arterial desaturation while asleep, that are more severe and / or more frequent that subjects who have had a stroke but do not aspirate.

It was decided for logistical reasons, that subjects would not be studied within the first six weeks of having had a stroke as they may well be medically unstable during this time or may be experiencing a rapid recovery. The hypothesis will be tested against a sample of subjects who have sustained a stroke more than six weeks from the time of their participation in this study. These subjects will have undergone videofluoroscopy to determine whether they are aspirating or not when eating or drinking. All study participants will

have their arterial oxygen saturation measured non-invasively over the course of a night while they are sleeping.

6.00 CHAPTER 6: Methodology Study 2

In this chapter the methodology used to collect data on the different patterns of nocturnal oxygen saturation in the dysphagic and non dysphagic patient will be described. This was an addendum to the original study and was also approved by the Southampton and South West Hampshire Ethics Committee and the Salisbury Research Ethics Committee and also by the Wellcome Trust Clinical Research Facility's scientific committee. The chapter is divided into the following sections:-

- The study design
- The study procedure
- Patient selection
- Patient recruitment
- The final protocol

6.01 The Study Design:

It was proposed to undertake a further pilot study. A series of 10 individual case studies, in which subjects with sub-acute stroke would be monitored during a single nights sleep by nocturnal pulse oximetry. These subjects were recruited from the first study and the nocturnal oximetry assessment was undertaken within 48 hours of the videofluoroscopy study. Of the 10 patients 5 would be known to have dysphagia resulting in aspiration as seen on videofluoroscopy. The remaining five would have no evidence of aspiration on videofluoroscopy. Baseline information regarding their lung function profile, smoking history, collar size and snoring history had all been recorded during their videofluoroscopy. Smokers were recorded as never, given up (stopped smoking longer than 5 years, length of time smoking and number of cigarettes were also recorded) or current. Snorers were recorded as never, don't know (this was a response given sometimes by subjects who lived alone), occasional (subjects would say that they snore up to 3 days a week but it was usually when they had had for example an alcoholic drink or had a cold, or snorer (this was someone who snored every night).

This part of the study was designed in consultation with Sue High, Medical Statistician at the University of Southampton. The study took place in the Wellcome Trust Clinical Research Facility (WTCRF) at Southampton General Hospital.

6.02 Patient recruitment:

All the patients who were selected for this trial had undergone an NHS instigated videofluoroscopy for an investigation into possible dysphagia. The researcher then approached consecutive sub-acute stroke patients (out-patients only at Salisbury District Hospital) and in and out-patients at Southampton General Hospital with an information sheet about this stage of the study. When 5 aspirating and 5 non-aspirating stroke patients had consented to undergo nocturnal oxygen saturation monitoring then recruitment to the study was stopped.

6.03 The inclusion and exclusion criteria:

For the patient selection the inclusion criteria were:
1. A clinical diagnosis of sub-acute (greater than 6 weeks post onset) cerebral vascular accident – not necessarily confirmed by CT.
2. To have attended a videofluoroscopy assessment at either Southampton General Hospital or Salisbury District Hospital and have a formal diagnosis of ability to swallow. The diagnosis would be as follows: non-aspirator (no evidence of food or fluid passing below the level of the vocal cords or aspirator (food or fluid is seen to have passed below the level of the vocal folds on videofluoroscopy).

The exclusion criteria for the sleep study were as follows:
1. In-patients who were considered by their medical team to still be too medically unstable to spend a night away from the medical ward.
2. Patients with severe uncontrolled Raynaud's Disease who at the time of study had an absent palpable radial pulse.

Patients were approached either as in or out-patients after attending the first part of the study in the videofluoroscopy suites of Southampton General Hospital or Salisbury District Hospital. They were given an information sheet by the researcher with a prepaid envelope and asked to consider their decision for at least 24 hours before returning the consent forms. If they required further information before consenting there was a telephone number and contact address on the enclosed information letter.

Assurances were given that the patient information gathered during the course of the study would be treated as confidential and stored in a secure place.

6.04 The protocol:

The study procedure:

Subjects came to the WTCRF in the early evening. They were greeted by the investigator and a named study research nurse. The eligibility for the study was checked and the informed consent form was checked for signatures. The patient sat with their friends or family in the lounge of the unit until they were ready for bed. Their normal evening routine was maintained as much as possible.

The study subjects stayed overnight in the WTCRF. When they were ready to go to bed the research nurse placed the pulse oximeter probe on the affected side ring finger. The subjects' oxygen saturation levels were taken using the same Nellcor N595 pulse oximeter used during the videofluoroscopic examination. The cable was loosely looped around the wrist to help stabilise the probe head. If the subject was wearing nail polish this was removed prior to the placement of the probe with a non-alcohol based polish remover. The oximeter was mounted away from the subject's view and all alarms were turned off. The oximeter was turned on and the monitor at the nurses' station was checked against the one at the bed side. The subjects were left to go to sleep. If the alarm became dislodged during the night, it was replaced and the time was noted by the research nurse. The data were recorded on the

pulse oximeter for analysis later. They were continuously monitored by a trained nurse. The investigator also stayed at the WTCRF in the on call medical staff room, in case of emergencies but was not involved in data collection. This was an attempt to avoid bias. Medical cover was provided by the on call medical team.

When the patient woke in the morning the nurse turned off the pulse oximeter and the probe was removed. The information was downloaded from the pulse oximeter onto a Dell Inspiron 8200 laptop computer using the software package Score and the information regarding dislodged probes during the night was also added. Information is produced in a data sheet showing heart rate, oxygen saturation levels and movement every five seconds. The software was set to record falls in oxygen saturation levels of 4% or more from 95%.

6.06 Potential weaknesses in the study design:

This study's design could be criticised because the subjects' oximetry data were only recorded over a time period of one night. This may mean that data recorded is not representative of the subjects natural sleep state. This may also be exacerbated by the fact the studies took place in the Wellcome Trust rather than at the subjects home. The sample size is also very small and results from it should be interpreted with caution.

6.07 Data analysis:

The following statistical analysis were used:

The data collected in this study were used to demonstrated the number of desaturation episodes which occurred when the subjects was asleep. The duration of each individual desaturation episode was recorded as were their combined duration. The data of aspirating and non aspirating subjects were explored using Box and Whisker plots allowed visualisation of symmetry, skewness and outliers. This was then combined with tests of normality to

decide between parametric and non parametric testing. Comparisons were then made using Mann-Whitney U tests between aspirating and non aspirating subjects as the sample size was so small.

The analyses were performed using the statistical computer programme SPSS 11.00. The criterion for statistical significance was that when the p value was equal to or less than 0.05. However this low level of statistical significance still runs the risk of producing type one errors therefore a more stringent significance level was required for more confidence therefore p=.01 at the 1% level and p=.005 at the .5% level were also included.

7.00 CHAPTER 7: Results – Study 2

This chapter presents the results of the observational pilot study of the patterns of nocturnal oximetry in aspirating and non aspirating subjects. The results are divided into the following subsections:

i. Subject demographics
ii. Desaturation episode information

A total of ten subjects were recruited. They were divided equally into two study groups aspirating and non aspirating. The subjects demographic details are summarised in tables 7.01, 7.02 and 7.03

Table 7.01: **Clinical Information**

ID	Age (yr)	Sex	Stroke	Asp /Non Asp	Collar (cm)	Smoker	Snorer
1	75	M	L Cerebellar (i)	A	42	Given Up	SNORER
2	76	F	L Cerebellar (i)	A	33	Given Up	OCCASIONAL
3	83	M	R MCA (h)	A	39	Given Up	NEVER
4	67	M	R Cerebellar (i)	A	37	Given Up	NEVER
5	83	M	L Lacunar (i)	A	37	Given Up	D/KNOW
6	90	F	RMCA (i)	NA	33	Given Up	OCCASIONAL
7	36	M	R Cerebellar (i)	NA	45	Current	SNORER
8	86	M	L Cerebellar (i)	NA	38	Given Up	NEVER
9	68	M	L Lacunar (i)	NA	41	Current	NEVER
10	47	F	L MCA (h)	NA	47	Never	NEVER

A = Aspirator, NA= Non Aspirator, R=Right, L=Left, i=infarct, h=haemorrhage, MCA= middle cerebral artery

Table 7.02: Spirometry data recorded prior to eating or sleeping:

Groups	ID	FVC (l)	Predicted FEV_1 (l)	FEV_1 (l)	FEV_1% (FEV_1/FVC)	PEF (ls)	MEF_{25-75} (ls)
Group 1	1 (ASP)	2.40	3.03	2.35	97	277	3.35
	2(ASP)	2.38	2.70	2.0	84	205	2.21
	3 (ASP)	4.40	2.59	3.56	80	493	2.94
	4(ASP)	1.98	2.66	1.38	69	134	.94
	5 (ASP)	3.10	2.71	.86	28	64	.26
Group 2							
	6 (NON ASP)	1.71	.93	1.06	61	91	.54
	7(NON ASP)	3.98	4.24	2.10	52	151	1.40
	8(NON ASP)	2.37	2.41	1.69	71	179	1.11
	9 (NON ASP)	3.35	3.19	2.64	78	362	2.20
	10(NON ASP)	2.34	1.77	1.77	75	231	1.22

Table 7.03: Mean Spirometry data comparing aspirating and non aspirating subjects

	disorder	Mean	Std. Deviation
FVC	aspirating	2.84	.96
	non aspirating	2.76	.899
FEV_1	aspirating	1.98	1.04
	non aspirating	1.90	.58
FEV_1%	aspirating	69.80	25.59
	non aspirating	69.20	12.87
PEF	aspirating	239.80	164.06
	non aspirating	197.60	101.20
MEF_{25-75}	aspirating	1.78	1.39
	non aspirating	1.49	.72

Mann-Whitney U tests were used to analyse the subjects' spirometry data which was recorded prior to eating, drinking or sleeping.

Table 7.04: Mann-Whitney U tests comparing aspirating and non aspirating subjects spirometry data recorded prior to eating or sleeping:

	z	df	Exact Sig.	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
FVC	-.104	8	1.00	.086	-1.27	1.44
FEV_1	-.104	8	1.00	.086	-1.14	1.31
$FEV_1\%$	-.313	8	.841	.60	-28.94	30.14
PEF	-.313	8	.841	42.20	-156.59	240.99
MEF_{25-75}	-.104	8	1.00	.29	-1.33	1.90

The above table demonstrates there were no significant differences in lung function between the two study groups prior to undertaking nocturnal pulse oximetry

7.01 Desaturation episode information

Data were recorded for the duration of individual episodes of desaturation (see tables 7.05 and figure 7.01). The frequency of desaturation episodes during an averaged 8 hour period was also recorded (see tables 7.06, and figures 7.02, 7.03 and 7.04), this was subdivided into episodes below 95%, 92% and 90% oxygen saturation level manually by the researcher. The total duration of desaturation was also recorded, as averaged over an 8 hour period (see table 7.08) and again this was sub divided into time below 95%, 92% and 90% oxygen saturation level. Individual episodes of desaturation were 4% below 95%, 92% and 90%. These were generated automatically by the Score software.

Table 7.05: Table comparing the mean duration of individual desaturation episodes between aspirating and non aspirating subjects.

	Aspirator Group 1	Non Aspirator Group 2	z	Exact Sig.	Mean Difference	95% Confidence Interval of the Difference	
						Lower	Upper
mean	76.7 seconds	49.7 seconds	2.1	.095	26.99	-2.50	56.48

Figure: 7.01: Box and whisker plot demonstrating median and interquartile range of duration of individual episodes of desaturation in aspirating and non aspirating subjects.

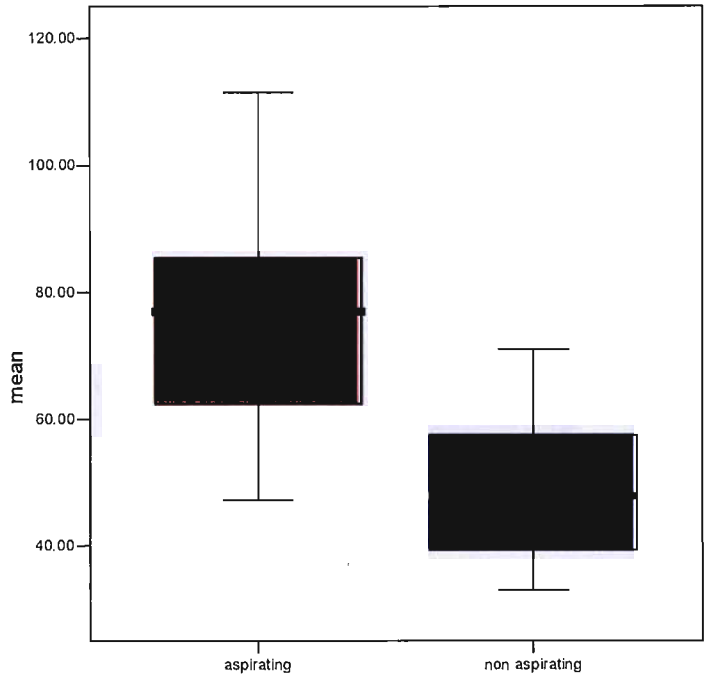
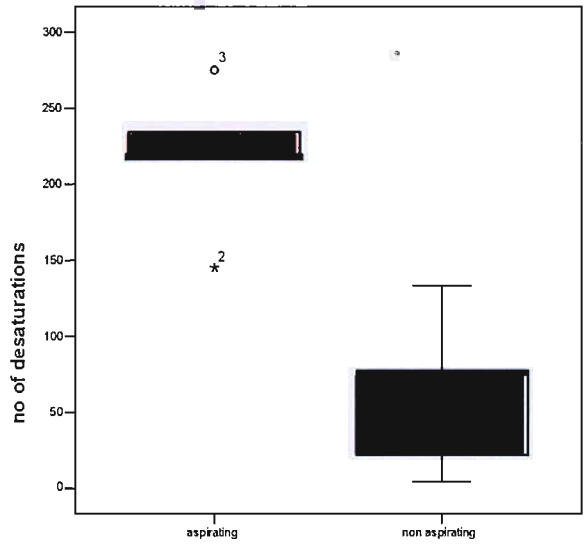


Table 7.06: Table comparing mean frequency of desaturation episodes (lasting more than 5 seconds) in an average 8 hour period between aspirating and non aspirating subjects

			z	Exact Sig.	Mean Difference	95% Confidence Interval of the Difference	
No. of desaturations below	Aspirating Group 1 (n=5)	Non Aspirating Group 2 (n=5)				Lower	Upper
95%	218	62	-2.611	.008	155.4	83.84	226.96
92%	132	27	-2.460	.016	105.2	57.42	152.98
90%	124	27	-2.619	.008	96.5	57.92	135.08

Figure 7.02: Box and whisker plot showing median and interquartile ranges of number of desaturation episodes at 95% oxygen saturation level or below



° = outlier (id no given)

* = extreme outlier (id given)

Figure 7.03: Box and whisker plot showing median and interquartile ranges comparing number of episodes of desaturation at 92% oxygen saturation level or below for aspirating and non aspirating subjects

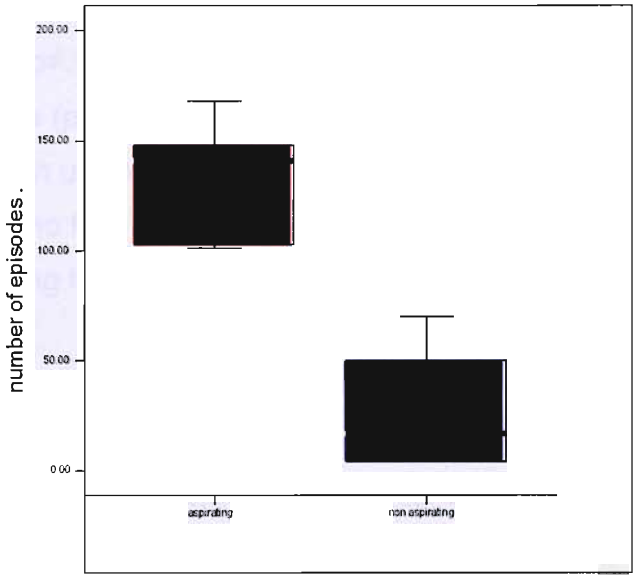
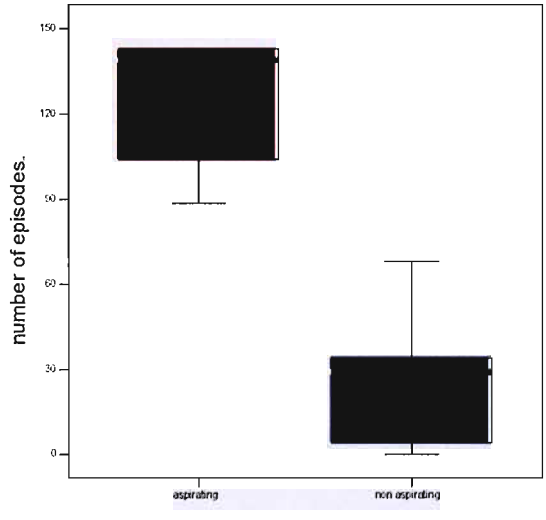


Figure 7.04: Box and whisker plot showing mean and interquartile ranges comparing number of episodes of desaturation at 90% oxygen saturation level or below for aspirating and non aspirating subjects.



Ten subjects (5 aspirating, 5 non-aspirating) undertook night oximetry studies. The aspirating subjects were on average older than the non aspirating subjects

(76.8 yrs compared with 65 years). Mann-Whitney U showed that this was not statistically significant p=.841. There was no difference statistically in the sizes of the subjects' collar size (p=.421. All members of the aspirating group were smokers who had given up. Members of the non aspirating group were a mix of non smokers, those who had given up and current smokers. The groups were well matched for snoring history (table 7.01).

Baseline resting spirometry information (table 7.02) was analysed to compare the aspirating and non aspirating subjects. Data were explored using box and whisker plots and using tests of normality to look for distribution patterns on the basis of this, and the size of the subject group, the decision was made to use non parametric tests. Mann-Whitney U tests demonstrated that there were no such differences and it can therefore be assumed that there were no significant differences in the subjects' respiratory function when awake.

Unless stated otherwise data were averaged over an 8 hour period of time. Information gained from the nocturnal oximetry using Mann-Whitney U tests demonstrated that aspirating subjects had a high frequency of episodes of desaturation below 95% SO_2 levels compared with those who did not aspirate (218 compared with 62) (p=.008). This pattern was replicated in falls below 92% (132 compared with 27) and 90% of oxygen saturation (124 compared with 27) (p=.016 and p=.008) (see table 7.06). The aspirating subjects spent longer desaturated than non aspirating subjects both below 95% SO_2 (179.5 minutes compared with 29 minutes) and 92% SO_2 (31.5 minutes compared with 0.8 minutes) (see table 7.08) .The length of each individual episode of desaturation was also longer in the aspirating subjects (76.7 seconds compared with 49.7 seconds) (see table 7.05).

Table 7.08: Comparison between aspirating and non aspirating subjects mean (SD) duration of time spent desaturated, in an averaged 8 hour period.

			z	Exact Sig.	Mean Difference	95% Confidence Interval of the Difference	
	Aspirating (n=5)	Non-Aspirating (n=5)				Lower	Upper
Below 95%	179.5 mins	29 mins	-2.611	.008	150.41	39.97	260.86
Below 92%	31.5 mins	0.8 mins	-2.491	.016	30.74	1.50	59.99
Below 90%	16.8 mins	0.8 mins	-2.200	.032	15.998	-6.299	38.29

Figure 7.05: Box and whisker plot showing median and interquartile ranges comparing aspirating and non aspirating subjects total duration of time spent desaturated below 95%

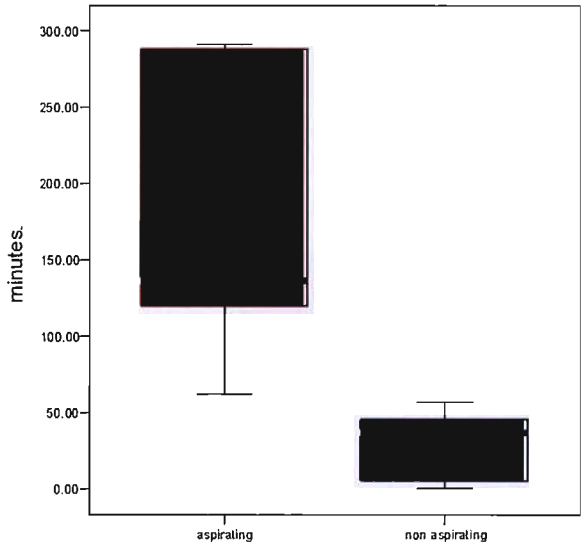


Figure 7.06: Box and whisker plots showing median and interquartile ranges comparing aspirating and non aspirating subjects total duration of time spent desaturated below 92%

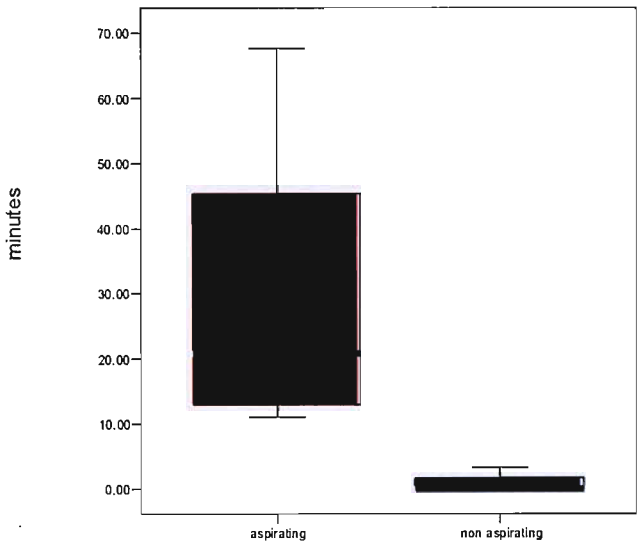
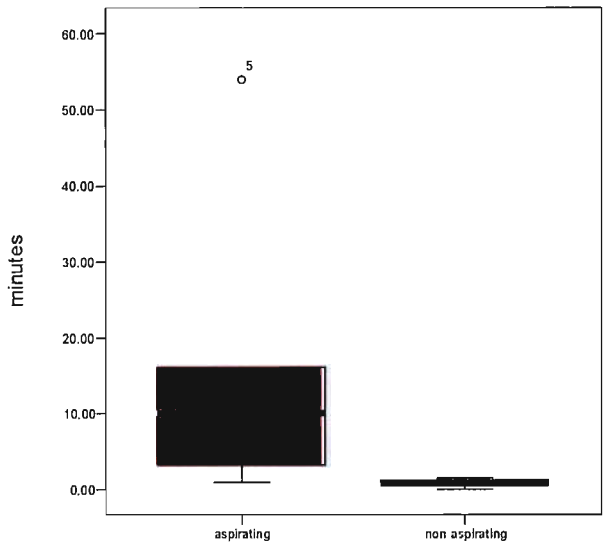


Figure 7.07: Box and whisker plot showing median and interquartile ranges comparing aspirating and non aspirating subjects total duration of time spent desaturated below 90%



° = outlier (id no. given)

Aspirating subjects had lower average levels of oxygen at night (94.8%) compared with non aspirating subjects (96.6%) although this was not statistically significant. Both groups also demonstrated significant falls at night in the level of

oxygen (aspirating subjects 75.2% compared with non aspirating 83%) but again this was not statistically significant. The aspirating group moved around far more at night (19.8% of the study) compared with the non aspirating group (9.4%), but this was not found to be statistically significant. (see tables 7.10 and figure 7.08). Periods of movement tended to be clustered at the ends of episodes of desaturation.

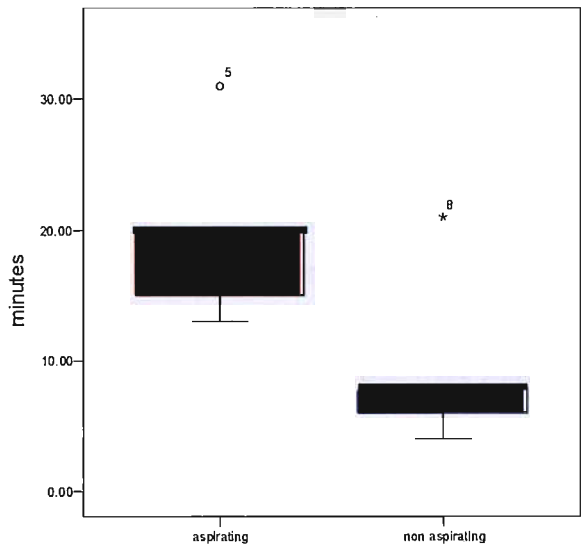
Table 7.09: Table comparing mean baseline and lowest oxygen saturation levels in aspirating and non aspirating subjects during an average 8 hour period.

Average oxygen saturation level						95% Confidence Interval of the Difference	
	Aspirating Group 1	Non aspirating Group 2	z	Exact Sig.	Mean Difference	Lower	Upper
Lowest level	75%	83%	-1.471	.151	-7.80	-20.61	5.01
Average level	95%	97%	-2.00	0.95	-1.8	-3.73	..13

Table 7.10: Table comparing mean time spent moving as percentage of whole night whilst sleeping in aspirating and non aspirating subjects

Average Time Spent in Motion		z	Exact Sig.	Mean Difference	95% Confidence Interval of the Difference	
Aspirators Group 1	Non Aspirators Group 2				Lower	Upper
19.8%	9.4%	2.41	.095	10.40	.428	20.372

Figure 7.08: Box and whisker plot showing median and interquartile ranges comparing aspirators and non aspirators time in motion



° = outlier (id no. given)

* = extreme outlier (id no. given)

7.02 Summary of results:

Aspirating subjects desaturate more frequently, for longer periods of time and to a greater degree than non aspirating subjects.

8.00 CHAPTER 8 – Discussion Study 2

The aim of the second pilot study was to compare the nocturnal oximetry data of aspirating and non aspirating stroke patients (lasting longer than 6 weeks). There have been previous reports of the occurrence of respiratory dysfunction in stroke patients (Oksenberg 2003, Bassetti 1999) and of the prevalence of dysphagia in stroke (Gordon 1987). This study is the first to use continuous nocturnal pulse oximetry to compare the desaturation patterns of aspirating and non aspirating subjects and has built on the work with acute strokes of Sulter et al (2000). This study utilised the gold standard videofluoroscopy instead of the previously used non standardised method of assessment and directly compares known aspirating subjects with non aspirating subjects.

This was a small study group who were only assessed over one night. This may mean that any results gained may not reflect the general dysphagic stroke population but be a chance finding. There was an attempt by the researcher to age and sex match the dysphagic and non dysphagic stroke patients. This may have led to some bias in the selection. The study does not compare normal controls to known aspirating dysphagic patients and it is recognised that non aspirating stroke patients may still have abnormalities in their sleep patterns. The majority of the patients attending the overnight study were outpatients, by selecting this group there is a bias in the fact that these patients are likely to be physiologically healthier than inpatients. Unfortunately the WTCRF does not have its own medical team to take responsibility for the more medically "sicker" patients.

The study did not use plethysmography or continuous arterial blood oxygen and carbon dioxide monitoring. The former was not available to the researcher and the latter is considered invasive and therefore potentially distressing to patients. These methods are considered the "gold standard" of respiratory assessment.

Coates (1993) reports however that patients often sleep fitfully as a consequence of these measurements. The researcher only had a limited amount of time in the research facility and therefore it was important that any patient information gained was as representative of normal as possible. It was decided therefore that a non invasive method of assessment may yield fewer results but that they may be more representative of the patients' true respiratory patterns.

The subjects recruited to this study were stroke patients (of 6 weeks or longer duration), characterised by aspiration or non aspiration as seen on videofluoroscopy. The study group were small in number and the subjects should also be seen as individual cases and these results are not necessarily generalisable to the larger population. A larger fully powered study would be needed to confirm / refute the results found. The subjects recruited for the study were taken from consecutive videofluoroscopy referrals. The average age of the aspirating subjects was 77 years compared with 65 years. This disparity in age may reflect the risk of stroke, and disability increasing with age. The groups were well matched for collar size and snoring history. The groups were slightly different in smoking history. In a larger study it may be important that these factors are closely matched to try and assess which desaturation events are due to aspiration and which may be due to obstructive sleep apnoea syndrome.

The results of the trial have demonstrated that aspirating subjects have statistically significantly more episodes of oxygen desaturation than non aspirating subjects when asleep. It has also demonstrated that aspirating subjects individual episodes of desaturation have a longer duration than non aspirating subjects and that the total length of time spent desaturated is longer for aspirating subjects than non aspirating subjects. It has also shown that aspirating subjects move around more at night than non aspirating subjects. The oximeter had only a limited method of recording the subjects' movement but, the aspirating subjects periods of sustained hypoxia were always followed by movement, as witnessed by the research nurse. Without a full sleep assessment

it cannot be said with certainty that the prolonged hypoxia (or possibly hypercapnia) causes the subject to rouse, but it seems likely. This may mean that aspirating subjects will spend less time in deep REM sleep than non aspirating subjects. Gall et al (2003) examined the relationship between subjects with Alzheimer's disease and sleep disordered breathing and tentatively proposed a link between agitation and SDB although this was not linked to specifically nocturnal or day time agitation.

Nocturnal pulse oximetry:

Pulse oximetry is frequently used in night studies as a simple and reliable and non-invasive method of assessing oxygen saturation. The non aspirating subjects had a mean oxygen saturation level very similar to Gries and Brooks (1996) however the aspirating subjects had a lower baseline oxygen saturation level, even though this was not found to be statistically significant in such a small study. The computer recorded the oxygen saturation levels every 5 seconds which may mean that short hypoxic episodes may have been missed. There is no universally accepted definition of an oxygen desaturation in sleep disordered breathing which is why the author chose to look at oxygen saturation levels at 95%, 92% and 90%. Cooper et al (1991) as many other authors have, has expressed concern about the sensitivity and specificity of overnight pulse oximetry. They found that both sensitivity and specificity improved the greater the number of hypoxic events per hour (25 events per hour, the sensitivity was 100% and specificity 95%). This supports the findings in the aspirating group but the non aspirating groups results should be considered with caution (less than 5 events per hour 60% sensitivity and 80% specificity). Due to uncontrolled movement in sleep, movement artefact should also be considered when interpreting the percentage of movement recorded in the aspirating group as it is higher in overnight pulse oximetry compared with daytime oxygen saturation levels.

Stroke is the third leading cause of death and the most common cause of long term disability in the UK. It is also the most common pathology to cause dysphagia in the adult population. The prevalence of dysphagia after stroke ranges from 25% (Linden 1983) to 50% (Mann 2000). Aspiration (food, fluid or the patient's own secretions passing below the level of the true vocal cords) is common. Previous studies of aspiration have reported that even a single episode can lead to pneumonia, sepsis, dehydration and malnutrition. This has led to recommendations that all stroke patients should be accurately screened for dysphagia within 24 hrs of diagnosis or on admission and fully assessed within two working days of referral (SIGN 2002, SIGN 1997, SIGN 2004, Royal College of Physicians 2004). This assessment has been found difficult to provide in a large number of facilities due to either the lack of trained staff or the specialist equipment to do so (videofluoroscopy). For an example in the Wessex region there is only one weekly videofluoroscopy clinic. Lack of an effective and available assessment is likely to result either in patients not being fed or hydrated, being given oral food and fluid inappropriately, or being given alternative food and fluid (nasogastric or percutaneous feeding tubes) inappropriately. This could have serious implications for increased mortality and morbidity in the patient with dysphagia. Up to one third of alert stroke patients with dysphagia are reported to die within the first six months following stroke, compared with fewer than 10% of other alert stroke patients (Barer 1989).

Patients with stroke are also at risk of hypoxia due to weakness of respiratory muscles and damage to the central respiratory control centres. Although patients are routinely assessed for their oxygen saturation at admission, further long term monitoring is not usually deemed necessary. Sleep related breathing disorders such as obstructive apnoeas and central apnoeas have been reported in up to 90% of stroke patients (Harbison 2002, Parra 2000, Good 1996). It is possible that nocturnal hypoxia could easily be missed in patients who have stroke largely because they rarely complain of any symptoms. This may be

because they are aphasic (unable to speak or express themselves), have or are suspected of having cognitive changes (so concentration and problem solving skills are reduced), have a depressive mood state (depression is a well documented after stroke) and may have an increased physical burden such as a hemiplegia and so are expected to be more tired and sleepy. Alterations in oxygen saturation during sleep may result in excessive daytime sleepiness, inattention and irritability and impaired cognitive function, delirium, depressed mood and reduced ADL and all mimic expected post stroke sequelae. All of these symptoms may lead to at best an increased time in rehabilitation and at worst a reduced prognosis (Sandberg 2001). Several studies have also suggested a link between heavy snoring; sleep disordered breathing and cerebrovascular disease with snorers having both worse short and long-term outcomes (Spriggs 1992).

Roffe (2003) assessed 100 acute stroke patients compared with controls for nocturnal hypoxia and found 38% of stroke patients had significant nocturnal hypoxia. In an initial study (Sulter et al 2000) assessed for 48 hours, subjects with acute stroke, for hypoxia which when found they treated with oxygen via nasal prongs. They found 63% of their subjects developed hypoxia and this was correlated to stroke severity, age and a failed informal swallowing screening of sipping a teaspoon of water. This led the team to believe that desaturation was either due to hypoventilation due to impairment of the movements of the chest wall and diaphragm or to neurogenic pulmonary oedema.

Sleep apnoea is also commonly found in stroke and has thought previously to be the cause of nocturnal desaturation in this disorder, but our study demonstrates clearly, by looking at stroke patients as 2 discreet groups (aspirating and non aspirating subjects), that there is a difference between the patterns of desaturation between the groups. The spirometry data showed there was no difference before sleep between the two groups. There was no difference between the collar sizes of the two groups. It seems unlikely therefore that sleep

apnoea could have been the cause of the desaturation episodes in the aspirating subjects.

Another possible mechanism for desaturation to be considered is gastroesophageal reflux which is common in sleep disordered patients and has also been linked to asthma. Multiple studies have studied nocturnal gastroesophageal reflux but have been unable to link it to nocturnal desaturation or changes in spirometry (Ozturk 2003, Ing 2000, Field 1999). It would appear therefore that gastroesophageal reflux is unlikely to be the cause of the desaturation in this study unless chronic aspiration exacerbates the bronchoconstriction effect by damage to the lungs.

Aspirating patients may be more at risk of hypoxia due to reduced pharyngeal and laryngeal reflexes but this cannot wholly provide an explanation as other studies have shown that "normal" healthy subjects also aspirate at night (Silver 1997). If normal healthy subjects demonstrate microaspiration of saliva at night but this does not result in desaturation, we must surmise that microaspiration is a normal process which is not detrimental to the body. Teramoto et al (1999) compared the swallowing reflex of subjects with OSAS with age matched controls to study the relationship between swallow function and sleep disorder. They found that subjects with disordered breathing took a greater volume of water to trigger the swallow reflex than controls and started to breathe again more quickly post swallow than controls. This would mean that such patients were potentially at risk of aspiration as the swallow may not have completely "finished" before the larynx is open to start breathing. In the stroke patient this system could become compromised and the mechanism be overwhelmed leading to episodes of desaturation. This may be an indicator for mechanism of effect and would imply a neurological basis for the desaturation such as that suggested by Teramoto who sites 'impaired function of afferent nerves to the higher brain, including the respiratory and swallowing centres'.

This study shows that aspirating stroke patients are clinically at risk of severe hypoxia during sleep and may support Roffes (2003) study which found hypoxia in sleeping stroke subjects. Nishino et al (1986) suggested that the presence of hypoxia itself may depress the swallowing reflex. Considering the S shaped curve relation between arterial oxygen tension and oxygen saturation small decreases in oxygen saturation in the patient groups studied reflects a considerable change in oxygen tension. The primary response of the peripheral tissues to hypoxia is vasodilatation but this causes a rapid reaction by the body by increased sympathetic activity. This leads to vasoconstriction and increased peripheral resistance. Sleep related hypoxia may also impair cardiac function and rhythm with both impaired right heart function and pulmonary venous congestion. Fletcher et al (1992) reported results from a multi-centred trial that subjects with untreated nocturnal hypoxia appeared to have a higher risk of death than controls or treated subjects. In subjects with established coronary heart disease the coexistence of sleep disordered breathing and resultant hypoxaemia has been shown to precipitate acute ischaemic events (Franklin et al 1995).

In further animal studies Bishop et al (2000) found that rats subject to hypoxia lost weight, implying that hypoxia has an effect on metabolism, caused disturbances in circadian rhythms and effected the animals ability to maintain a steady body temperature. McGuire and Bradford (2001) again studied rats and treated with alternating periods of hypoxia and normoxia for 5 days a week for 5 weeks to mimic sleep disordered humans. They replicated findings by Bishop that hypoxic rats lose weight compared with controls. They found an increase in mean systemic arterial blood pressure compared with controls but no effect on heart rate. There was also an increase in haematocrit and pulmonary arterial pressure compared with controls. Right ventricular hypertrophy was also found in the hypoxic group. Studies such as these demonstrate the detrimental effect of hypoxia.

Patients who aspirate demonstrated significant episodes of desaturation. As previously discussed, there are a number of possible mechanisms relating aspiration to a fall in oxygen saturation levels. However at present it is not known whether there is any direct causal association between aspiration and desaturation while sleeping.

9.00 CHAPTER 9 – Conclusions and recommendations Study 2

Chapter nine provides the main conclusions drawn from the study and lists the recommendations for further research and possible clinical practice.

9.1 Conclusions:

- Aspirating subjects desaturate for longer periods at night than non aspirating subjects.
- Aspirating subjects desaturate more frequently than non aspirating subjects below 95%, 92% and 90% oxygen saturation levels when asleep.
- Aspirating subjects have longer individual episodes of desaturation than non aspirating subjects when asleep.
- Aspirating subjects spend longer time in motion when asleep than non aspirating subjects.

9.2 Recommendations for further research:

Even though small in numbers these studies have demonstrated a large and currently untreated clinical problem which could affect stroke rehabilitation. These pilot studies clearly demonstrate a difference between aspirating and non aspirating stroke subjects and a strong correlation between aspiration and desaturation. The author suggests that severe nocturnal desaturation may be one of the reasons why dysphagic patients have a poorer response to rehabilitation. Kaneko et al (2003) compared stroke subjects with similar levels of disabilities but in addition some had OSAS and suggests that sleep apnoea may be contributing to functional impairment and prolonged hospitalisation after stroke. Unfortunately the paper does not specify which subjects had dysphagia. The aspirating subjects in the study group were no more disabled than the non-aspirating group (this was not formally assessed) except in their ability to swallow. The results of the second pilot study suggest that there should be larger trials with dysphagia and non dysphagic stroke

patients with nocturnal pulse oximetry assessing for nocturnal hypoxia and if found a further study should investigate the active treatment of the hypoxia. In the majority of patients arterial oxygen saturation has been demonstrated to be quickly restored with low flow oxygen therapy with nasal prongs as a route of administration (Sulter 2000).

Studies are now required to assess the clinical consequences of nocturnal desaturation in the stroke patient and in particular to assess the potential differences in rehabilitation outcome between the hypoxic and non hypoxic stroke patient. Small studies have already been undertaken assessing nasal continuous positive pressure ventilation nCPAP for the stroke population as a whole. Sandberg et al (2001) randomised 63 acute stroke subjects (unfortunately there is no record or dysphagia in either group) to nCPAP or not for a period of 28 days (mean 4 hrs per night). Depression scores improved significantly in the treatment group compared with the controls as did the measure of delirium. Barthel scores did not change in either group but it is recognised that the Barthel has limitations on its ability to detect small amounts of change. Wessendorf et al (2001) studied 105 subjects who had a non acute stroke with OSAS, again dysphagia is not mentioned as a disability. They found a highly significant reduction in respiratory events and an increase in oxygen saturation in the treatment group. They also found a significant reduction in the amount of arousal subjects demonstrated at night and a reduction in night time blood pressure again in the treatment group. Disler et al (2002) studied 38 patients acutely after stroke treating 5 with nCPAP (again there is no mention of dysphagia) and found that the treated group's oxygen saturation level normalised and the treatment was tolerated well. Okanda et al (2000) reported that they reversed the impairment of swallowing function in two subjects with OSAS. Studies should now be undertaken with dysphagic stroke subjects.

If dysphagic stroke subjects respond in the same manner as patients who have received treatment for obstructive sleep apnoea or chronic obstructive pulmonary disease (COPD) , i.e. show improvements in fatigue, impaired cognitive function and improved memory function (Incalzi et al 1993, Bedard

et al 1991, Aloia et al 2003), we could expect to see significant improvements in their rehabilitation outcome. A parallel study should be undertaken looking at a non neurological dysphagic population such as head and neck surgery to look for similar findings. EEG could be used to measure the proportion of REM and NREM sleep each subject has and compare this to normal studies. This study found that dysphagic subjects move more than non dysphagic subjects during sleep and as such may have a reduced amount of REM sleep. This may also be linked to hypoventilation and full sleep laboratory assessment would be able to investigate this fully.

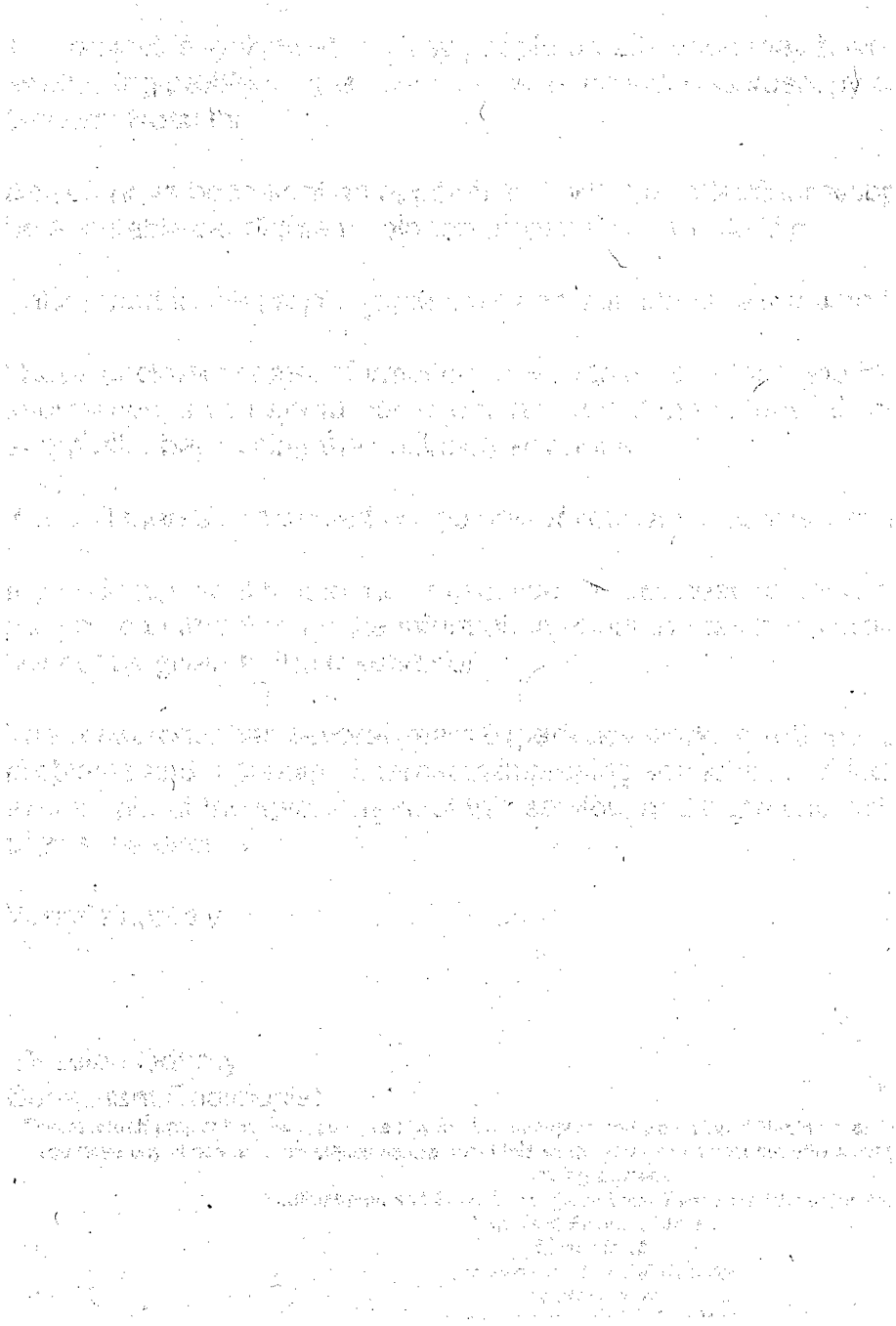
Nocturnal oximetry also may have a potential diagnostic role in established stroke subjects as an easy and non invasive method of detecting aspiration in the stroke patient.

Further work also needs to be performed in this area assessing nocturnal carbon dioxide response in aspirating stroke subjects and comparing chronic and acute stroke patients in their nocturnal oximetry patterns.

The two pilot studies undertaken attempted to generate a set of indices to use at the bedside, which would enable a clinician to predict if a patient was aspirating food or fluid. The initial study demonstrated that using a combination of the measurement of collar size, snoring and oxygen saturation levels during eating and drinking gave an 80% sensitivity and specificity for predicting aspiration. Although clinicians may be able to increase their ability to predict swallowing problems by up to 40% if these indices are adopted, the results thus obtained are no better than previous pulse oximetry studies discussed in the literature review.

The second study showed that aspirating and non aspirating subjects have statistically significant differences in their patterns of oxygen saturation levels during sleep. The subject numbers in this study were small and so the author is unable to set clinical criteria but feels that the study needs to be urgently repeated with larger numbers and together with the addition of carbon dioxide

measurements. If the results were similar then this would provide a simple clinical algorithm which could be used by a multi-disciplinary audience.



10.00. CHAPTER 10 - Appendix A

Dear

This department is currently supporting a research project linked to the University of Southampton and funded by the NHS Executive – SouthEast. This project has been approved by Southampton and South West Hants Ethics Committee.

The project is looking at the way people breath when they have a possible swallowing problem. It is taking place in the videofluoroscopy clinic at Southampton General Hospital.

As you have been sent an appointment with the videofluoroscopy clinic you would be a suitable candidate to join the project if you would like.

Taking part in the project is painless and will add no extra time to your appointment.

I have enclosed some information for you to read. Once you have read the information, if you would like to join the project then please fill in the consent form and post it back using the enclosed envelope.

You will then be contacted on the day of your videofluoroscopy by the researcher.

If you do not want to join the project you will still need to come to your appointment, but you can throw away the information about the research project and your name will not be given to the researcher.

The researcher has several years experience working with people with swallowing problems and a genuine interest in improving services provided to them. We are excited about the involvement of this service, and hope you will appreciate the value of this research.

Yours sincerely

Dr Allan Odurny
Consultant Radiologist

This research project has been approved by the Southampton and South West Hants Local Research Ethics Committee. If you have any concerns of an ethical nature about this study, you can contact the ethics committee, in confidence, at the following address:
Southampton and South West Hants Local Research Ethics Committee
Trust Management Offices
Mailpoint 18
Southampton General Hospital
Temona Road
Southampton tel: 02380 794912

Appendix B

Patient Information Sheet

(Development and evaluation of predictive indices in neurogenic dysphagia)

An investigation into the relationship between breathing and swallowing in people with swallowing difficulties.

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Thank you for reading this.

What is the purpose of the study?
Many people have swallowing problems as a result of various diseases and conditions. At present the only sure way of seeing what is going wrong with a person's ability to swallow is to give them a moving x-ray called a videofluoroscopy. This study is trying to find new ways of assessing swallowing problems by monitoring what happens to peoples breathing when they swallow. It is hoped one day we may not need x-rays to assess swallowing problems.

To do this we will be observing peoples breathing patterns while they are having their videofluoroscopy. The study will run for approximately 18 months from January 2002.

Why have I been chosen?
We would like you to consider taking part because your doctor has referred you to the videofluoroscopy clinic for your swallowing problems.

Videofluoroscopy is currently the best way there is of studying people with swallowing problems. Some research has shown that it is possible to tell what sort of problem a person has by measuring their breathing patterns.

We are comparing the breathing of people with different medical conditions to their videofluoroscopy results. Your doctor has thought that you might be suitable for this important study.

We would like to recruit 204 people to take part in the study.

What will happen to me if I take part?
You will be given a copy of the information sheet and asked to sign a consent form, if you have not done so already. You will keep a copy of this. You will attend your videofluoroscopy clinic as usual. A researcher will see you while you are waiting to go in. You will be taken to a room opposite the x-ray room. They will ask you to blow in and out

of a cardboard tube and they will place a small light on your fingertip. This will not hurt and will not leave marks. They will ask you a few simple questions about your collar size and ask if you can cough.

A radiographer will then call you in to the x–ray room. They will introduce you to the team running the videofluoroscopy clinic. The researcher will also come into the x-ray room with you. During your videofluoroscopy you will be asked to keep the light on your finger. Once the doctor has finished your videofluoroscopy, we would want you to return to the room opposite the x-ray room. You will then be asked to blow in and out of the tube once more and then the study is finished. You can then go home.

What are the side effects from taking part?
There are no side effects to taking part in this study

What are the possible disadvantages and risks of taking part?
There are no disadvantages or risks in taking part.

What are the possible benefits from taking part?
There is no direct benefit from you taking part in this study however the information we get from this study may help us to treat patients with swallowing problems better in the future.

Will my taking part in this study be kept confidential?
All information, which is collected, about you during the course of the research will be kept strictly confidential. Any information about you which leaves the hospital will have your name and address removed so that you cannot be recognised from it.

What will happen to the results of the research study?
The results will hopefully be published at the end of the research study in a medical journal. If you would like we could notify you of what journal closer to the time. You will not be identified in any report or publication.

Who is organising and funding the research?
The NHS Executive -South East is funding this research.

Who has reviewed this study?
The Salisbury and Southampton & S.W. Hampshire Research Ethics Committees have reviewed this study.

Contact for Further Information.

If you would like further information you can call or write to
Morwenna Collins
School of Health Professions & Rehabilitation Sciences
University of Southampton
Highfield
Southampton.
Tel: 02380 595260
Thank you for your time and interest.

Appendix C

Centre Number:
Study Number:
Patient Identification Number for this trial:

CONSENT FORM

Title of Project: Development and evaluation of predictive indices in neurogenic dysphagia.
An investigation into the relationship between breathing and swallowing in people with swallowing difficulties

Name of Researcher: Morwenna Collins

Please initial box

1. I confirm that I have read and understand the information sheet dated January 02 (version 2) for the above study and have had the opportunity to ask questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reasons, without my medical care or legal rights being affect ☐

3. I understand that sections of any of my medical notes may be looked at by the researc .I give permission for the researcher to have access to my notes. ☐

4. I agree to take part in the above study. ☐

Name of patient	Date	Signature
Name of Person taking consent	Date	Signature
Researcher	Date	Signature

1 for patient, 1 for researcher, 1 to be kept with hospital notes

Consent Form Version 2, Feb2002
SA/40/2001

Appendix D

Ethics number SA 40/2002
Patient Information Sheet - appendix1
(Development and evaluation of predictive indices in neurogenic dysphagia)
An investigation into the relationship between breathing and swallowing in people with swallowing difficulties.

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Thank you for reading this.

What is the purpose of the study?
Many people have swallowing problems as a result of various diseases and conditions. At present the only sure way of seeing what is going wrong with a person's ability to swallow is to give them a moving x-ray called a videofluoroscopy. This study is trying to find new ways of assessing swallowing problems by monitoring what happens to peoples breathing when they swallow. It is hoped one day we may not need x-rays to assess swallowing problems.

To do this we will be:
1. Observing peoples breathing patterns while they are having their videofluoroscopy.
2. Observing peoples breathing patterns while they are sleeping.

The study will run for approximately 18 months from January 2002.

Why have I been chosen?
We would like you to consider taking part in this part of the study because:
1. We wish to study the breathing of people who have had a stroke.
2. Because you have already allowed us to record your breathing patterns while you had a videofluoroscopy study.

We would like to recruit 10 people to take part in this part of the study.

What will happen to me if I take part?
You will be given a copy of this information sheet and asked to sign a consent form, if you have not done so already. This is very similar to the forms that you have already signed. You will keep a copy of this.

You will come to the Welcome Trust Clinical Research Facility, C level Southampton General Hospital in the evening. This is a special area in the hospital, which is used only for research. It is very quiet. It has a kitchen, lounge and bedrooms as well as a small ward. If you normally eat, you can have a meal before you come or we can arrange an evening meal for you. The researcher and nurses will meet you and show you around. You (and a friend or family member if you would like them to be with you) can then sit in the lounge until you are ready to go to bed. Unfortunately we do not have the space to let your friend or member of the family stay with you overnight.

The nursing staff will assist you in getting ready for bed. They will place the same, small light on your fingertip as you had for the videofluoroscopy. This will not hurt and will not leave marks. This will remain on your finger all night.

The researcher and nurses will stay in the unit all night should you need any assistance and there are doctors available in the unlikely event of an emergency. In the morning the study has finished. We will help get up and dressed. We will provide breakfast, if you normally eat or help with any special food or medications. You can then go home.

What are the side effects from taking part?
There are no side effects to taking part in this study

What are the possible disadvantages and risks of taking part?
There are no disadvantages or risks in taking part.

What are the possible benefits from taking part?
There is no direct benefit from you taking part in this study however the information we get from this study may help us to treat patients with swallowing problems better in the future.

Will my taking part in this study be kept confidential?
All information, which is collected, about you during the course of the research will be kept strictly confidential. Any information about you which leaves the hospital will have your name and address removed so that you cannot be recognised from it.

What will happen to the results of the research study?
The results will hopefully be published at the end of the research study in a medical journal. If you would like we could notify you of what journal closer to the time. You will not be identified in any report or publication.

Who is organising and funding the research?
The NHS Executive -South East and Hope (Dean's contingency fund) are funding this research.

Who has reviewed this study?
The Salisbury and Southampton & S.W. Hampshire Research Ethics Committees have reviewed this study.

Contact for Further Information.

If you would like further information you can call or write to
Morwenna Collins
School of Health Professions & Rehabilitation Sciences
University of Southampton
Highfield
Southampton. Tel: 02380 595260 up to 5pm (answer machine after this time)

Thank you for your continued time and interest.

Appendix E

Ethics Number: SA 40/2001
Patient Identification Number for this trial:

CONSENT FORM (Appendix A)

Title of Project: Development and evaluation of predictive indices in neurogenic dysphagia.
"An investigation into the relationship between breathing and swallowing in people with swallowing difficulties"

Name of Researcher: Morwenna Collins

Please initial box

5. I confirm that I have read and understand the information sheet dated June 02 (appendix 1) for the above study and have had the opportunity to ask questions. ☐

6. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reasons, without my medical care or legal rights being affected. ☐

7. I understand that sections of any of my medical notes may be looked at by the researcher or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to my records. ☐

8. I agree to take part in the above study. ☐

Name of patient	Date	Signature
Name of Person taking consent	Date	Signature
Researcher	Date	Signature

1 for patient, 1 for researcher, 1 to be kept with hospital notes

Appendix:F

Table F-01

id	age	sex	disorder	Stroke type	height	weight	smoker	Collar size
2	30	1	1	Other	1.75	65.31	G	15.00
6	77	1	2	Not recorded	1.75	58.06	G	17.50
3	69	1	2	Not recorded	1.75	95.25	G	18.00
27	84	1	2	Not recorded	1.72	N/R	G	18.00
52	79	1	2	Not recorded	1.68	N/R	N	18.00
61	76	1	2	Not recorded	1.67	N/R	G	18.50
44	81	1	2	Posterior	1.70	N/R	G	14.50
58	67	1	2	Not recorded	1.65	N/R	G	14.50
77	69	1	2	Not recorded	1.67	N/R	G	14.50
21	88	1	2	Not recorded	1.72	57.10	G	15.00
25	69	1	2	Not recorded	1.69	60.33	G	15.00
51	66	1	2	Not recorded	1.84	N/R	G	15.00
60	86	1	2	Posterior	1.72	N/R	G	15.00
74	83	1	2	Not recorded	1.60	N/R	G	15.00
76	60	1	2	Not recorded	1.86	N/R	G	15.00
48	83	1	2	lacunar	1.74	N/R	G	15.50
5	89	1	2	Right MCA	1.75	82.55	G	16.00
13	79	1	2	Other	1.82	82.55	G	16.00
26	82	1	2	Not recorded	1.58	N/R	N	16.00
71	81	1	2	Not recorded	1.67	N/R	G	16.00
24	75	1	2	posterior	1.79	82.55	G	16.50
38	78	1	2	Small vessel	1.67	N/R	N	16.50
47	78	1	2	Not recorded	1.57	N/R	G	16.50
59	69	2	1	Not recorded	1.68	N/R	G	16.00
57	91	2	1	Right MCA	1.47	N/R	C	13.00
43	86	2	1	Not recorded	1.52	N/R	G	15.00
15	77	2	2	Rght MCA	1.58	34.02	N	12.00
20	79	2	2	Not recorded	1.67	57.15	G	13.00
54	47	2	2	other	1.64	N/R	N	13.00
55	78	2	2	Right MCA	1.67	N/R	G	13.00
7	72	2	2	Right MCA	1.51	50.00	G	13.50
40	85	2	2	Right MCA	1.60	N/R	G	13.50
75	82	2	2	Brainstem	1.62	N/R	G	14.00
49	89	2	2	Right MCA	1.61	N/R	N	15.00
56	75	2	2	Other	1.74	N/R	G	15.00
39	65	2	2	Left MCA	1.68	N/R	G	15.50
31	66	1	1	Lacunar	1.65	N/R	C	14.50
14	68	1	2	Lacunar	1.72	76.20	G	16.00
11	61	1	2	Right MCA	1.77	92.50	N	17.00
62	87	1	2	Not recorded	1.82	N/R	G	17.00
10	35	1	2	Brainstem	1.80	76.20	C	17.50
18	79	1	2	Left MCA	1.82	95.25	G	17.50
22	35	1	2	Brainstem	1.80	76.20	C	17.50
73	79	1	2	Left MCA	1.62	N/R	N	14.50
9	72	1	2	Brainstem	1.80	63.50	G	15.50
46	84	1	2	Not recorded	1.75	N/R	G	15.50
41	92	2	1	Not recorded	1.72	N/R	N	14.50

id	age	sex	disorder	Stroke type	height	weight	smoker	Collar size
64	75	2	2	Not recorded	1.52	N/R	G	13.00
67	70	2	2	Not recorded	1.63	N/R	N	16.00
28	79	2	2	Right MCA	1.62	N/R	G	17.50
16	83	2	2	Lacunar	1.65	50.80	N	13.50
29	81	2	2	Left MCA	1.53	N/R	N	13.50
23	85	2	2	Not recorded	1.62	50.80	N	14.00
30	64	2	2	Not recorded	1.72	N/R	G	14.50
4	61	2	2	lacunar	1.65	69.85	N	15.00
53	76	2	2	Not recorded	1.66	N/R	N	15.00
63	76	1	3		1.80	N/R	G	16.50
66	62	1	3		1.67	N/R	N	14.50
1	77	1	3		1.67	63.50	N	15.00
35	56	1	5		1.84	N/R	C	17.50
72	83	1	6		1.77	N/R	G	14.50
68	87	2	3		1.62	N/R	G	13.00
37	73	2	3		1.71	N/R	N	15.50
12	59	1	3		1.77	91.17	C	16.00
69	78	1	3		1.70	N/R	C	17.00
70	38	1	3		1.77	N/R	N	17.00
34	66	1	3		1.76	N/R	G	15.00
36	63	1	4		1.77	N/R	G	16.00
65	64	1	5		1.60	N/R	C	15.50
33	44	1	5		1.79	52.00	C	14.50
42	27	1	6		1.80	N/R	G	16.00
8	92	2	3		1.50	50.80	N	13.00
17	57	2	4		1.57	65.77	G	16.50
19	63	2	4		1.70	88.90	G	17.50
45	48	2	5		1.69	N/R	N	14.00
50	76	2	5		1.60	N/R	N	15.00

i.d.	snoring	Voluntary cough	Spontaneous cough	aspirator	Pre VF SO2	Post VFSO2	Difference SO2 post VF
2	N	N	N	aspirator	99	97	2
6	F	Y	N	Aspirator	98	96	2
3	O	Y	Y	Aspirator	98	89	9
27	D	N	N	Aspirator	95	89	6
52	D	Y	N	Aspirator	100	84	16
61	H	Y	N	Aspirator	98	95	3
44	O	Y	N	Aspirator	97	92	5
58	N	Y	Y	Aspirator	98	94	4
77	F	Y	N	Aspirator	97	93	4
21	N	Y	Y	Aspirator	99	96	3
25	H	Y	N	Aspirator	98	97	1
51	N	Y	N	Aspirator	100	95	5
60	D	Y	N	Aspirator	100	95	5
74	F	Y	N	Aspirator	98	96	2
76	F	Y	N	Aspirator	99	92	7
48	N	Y	N	Aspirator	98	97	1
5	O	Y	Y	Aspirator	99	97	2
13	F	Y	N	Aspirator	97	92	5
26	H	Y	Y	Aspirator	98	95	3

i.d.	snoring	Voluntary cough	Spontaneous cough	aspirator	Pre VF SO2	Post VFSO2	Difference SO2 post VF
71	H	Y	Y	Aspirator	98	95	3
24	H	Y	N	Aspirator	97	93	5
38	D	Y	N	Aspirator	98	94	4
47	N	Y	N	Aspirator	97	87	10
59	O	Y	N	Aspirator	100	99	1
57	D	Y	Y	Aspirator	100	97	2
43	H	Y	N	Aspirator	98	96	2
15	N	Y	N	Aspirator	96	94	2
20	O	Y	N	Aspirator	98	95	3
54	N	Y	N	Aspirator	100	99	1
55	F	Y	N	Aspirator	99	98	1
7	D	N	N	Aspirator	96	94	2
40	D	Y	N	Aspirator	99	97	2
75	N	Y	N	Aspirator	99	94	5
49	N	Y	N	Aspirator	97	94	3
56	N	Y	N	Aspirator	98	96	2
39	D	Y	N	Aspirator	98	93	5
31	N	Y	N	Non aspirator	98	97	1
14	N	Y	Y	Non aspirator	98	97	1
11	F	Y	Y	Non aspirator	100	99	1
62	O	Y	Y	Non aspirator	98	95	3
10	F	Y	Y	Non aspirator	98	97	1
18	O	Y	Y	Non aspirator	99	96	3
22	F	Y	Y	Non aspirator	99	98	1
73	N	Y	N	Non aspirator	95	92	3
9	F	Y	Y	Non aspirator	97	96	1
46	H	Y	Y	Non aspirator	98	97	1
41	N	Y	Y	Non aspirator	98	96	2
64	O	Y	Y	Non aspirator	98	95	3
67	N	Y	Y	Non aspirator	97	89	8
28	O	Y	Y	Non aspirator	95	94	1
16	N	Y	Y	Non aspirator	99	96	3
29	N	Y	N	Non aspirator	97	97	0
23	F	Y	Y	Non aspirator	100	92	8
30	O	Y	Y	Non aspirator	98	96	2
4	O	Y	Y	Non aspirator	97	94	3
53	N	Y	Y	Non aspirator	98	97	1
63	H	Y	N	Aspirator	98	95	3
66	O	Y	N	Aspirator	97	95	2
1	O	Y	N	Aspirator	99	79	20
35	D	Y	Y	Aspirator	97	95	2
72	D	Y	N	Aspirator	98	83	15
68	N	Y	N	Aspirator	97	93	4
37	N	Y	N	Aspirator	98	82	16
12	D	N	N	Non aspirator	97	95	2
69	F	Y	Y	Non aspirator	98	97	1
70	N	Y	Y	Non aspirator	94	84	10
34	F	Y	Y	Non aspirator	99	99	0
36	H	Y	Y	Non aspirator	97	96	1
65	O	Y	Y	Non aspirator	97	94	3

i.d.	snoring	Voluntary cough	Spontaneous cough	aspirator	Pre VF SO2	Post VFSO2	Difference SO2 post VF
33	N	Y	N	Non aspirator	96	95	1
42	O	Y	Y	Non aspirator	97	96	1
8	N	Y	Y	Non aspirator	95	94	1
17	O	N	N	Non aspirator	98	96	2
19	H	Y	Y	Non aspirator	98	98	1
45	N	Y	Y	Non aspirator	100	100	0
50	D	Y	Y	Non aspirator	97	95	2

i.d.	Predicted FVC	FVC pre VF	FVC% predicted	FVC post VF	% of predicted
2	4.96	5.01	101	5.27	106
6	3.74	1.41	38	1.68	45
3	3.95	N/R	N/R	4.06	103
27	N/R	N/R	N/R	N/R	N/R
52	3.11	1.32	42	0.94	30
61	N/R	N/R	N/R	N/R	N/R
44	3.35	1.85	55	1.75	52
58	3.42	1.98	58	2.68	78
77	3.48	2.94	84	3.11	89
21	3.28	1.83	56	2.80	85
25	3.60	4.05	113	4.61	128
51	4.54	4.18	92	4.79	105
60	3.33	2.37	71	2.17	65
74	2.72	2.14	79	1.82	67
76	4.87	2.59	53	2.02	41
48	3.52	4.40	125	4.91	139
5	3.42	2.72	80	3.13	91
13	4.09	3.20	78	2.56	63
26	1.98	0.53	27	0.77	39
71	3.17	1.85	58	2.22	70
24	4.02	2.40	60	2.53	63
38	3.31	3.48	105	3.11	94
47	2.67	1.61	60	1.74	65
59	2.76	2.61	95	2.54	92
57	1.26	1.71	136	1.89	150
43	1.61	0.42	26	0.74	46
15	2.11	2.13	106	1.66	79
20	2.45	2.17	89	2.30	94
54	3.15	2.38	76	2.27	72
55	2.48	2.23	90	2.19	88
7	N/R	N/R	N/R	N/R	N/R
40	2.17	0.77	36	0.78	36
75	2.24	1.10	49	1.18	52
49	1.93	0.59	31	0.99	51
56	2.87	2.60	91	1.97	69

i.d.	Predicted FVC	FVC pre VF	FVC% predicted	FVC post VF	% of predicted
39	Not recorded	Not recorded	N/R	N/R	N/R
31	3.45	2.80	81	2.86	83
14	4.14	3.35	81	3.59	87
11	4.27	3.33	78	2.42	57
62	3.88	1.35	35	1.51	39
10	5.12	3.98	78	3.33	65
18	4.09	3.11	76	3.67	90
22	5.12	4.93	96	4.82	94
73	Not recorded	Not recorded	N/R	N/R	N/R
9	4.27	2.79	65	2.67	63
46	3.56	2.94	83	3.13	88
41	2.34	2.29	98	1.73	74
64	1.89	2.34	124	2.62	138
67	2.29	1.58	69	2.15	94
28	2.94	2.82	96	2.52	86
16	2.11	0.78	37	0.54	26
29	1.78	Not recorded	N/R	N/R	N/R
23	2.80	0.50	24	0.48	23
30	3.07	2.27	74	2.22	72
4	2.83	2.12	75	2.04	72
53	2.49	1.41	57	1.30	52
63	4.05	4.99	123	4.96	122
66	3.67	2.59	71	2.72	74
1	3.33	Not recorded	N/R	3.11	93
35	4.86	2.86	59	3.07	63
72	3.70	3.01	81	3.19	86
68	2.15	0.86	40	0.66	31
37	3.87	0.78	20	0.28	7
12	4.32	2.42	56	2.01	46
69	3.42	2.80	82	2.63	77
70	4.75	1.99	42	1.60	34
34	3.45	6.32	183	6.14	178
36	4.22	4.58	109	4.22	100
65	Not recorded	Not recorded	N/R	N/R	N/R
33	4.83	3.60	75	3.70	77
42	5.33	4.49	84	4.22	79
8	1.41	2.40	145	2.05	146
17	2.58	0.30	12	0.44	17
19	3.00	1.51	50	2.94	98
45	3.35	4.18	125	4.64	139
50	2.27	0.83	36	0.78	34

i.d.	FEV1% predicted	FEV1% pre VF	%predicted post VF	% Predicted pre VF	FEV1% post VF
2	81.00	89.00	83	110	67.00
6	73.00	61.00	82	84	60.00
3	74.00	N/R	104	N/R	77.00
27	N/R	N/R	N/R	N/R	N/R
52	72.00	89.00	121	124	87.00
61	N/R	N/R	N/R	N/R	N/R
44	72.00	92.00	126	128	91.00
58	75.00	69.00	85	92	64.00
77	74.00	49.00	65	66	48.00
21	71.00	92.00	97	130	69.00
25	74.00	50.00	73	68	58.00
51	75.00	53.00	52	71	39.00
60	71.00	71.00	85	100	60.00
74	72.00	57.00	49	79	35.00
76	76.00	74.00	107	97	81.00
48	72.00	80.00	107	111	77.00
5	71.00	74.00	90	104	64.00
13	72.00	69.00	47	96	34.00
26	73.00	73.00	101	100	74.00
71	72.00	70.00	88	97	63.00
24	73.00	97.00	104	133	76.00
38	73.00	89.00	119	122	87.00
47	73.00	38.00	55	52	40.00
59	75.00	73.00	101	97	76.00
57	71.00	61.00	80	86	57.00
43	72.00	73.00	63	101	45.00
15	74.00	63.00	116	85	86.00
20	74.00	57.00	69	77	51.00
54	80.00	84.00	108	105	86.00
55	74.00	39.00	81	53	60.00
7	N/R	N/R	N/R	N/R	N/R
40	74.00	68.00	81	92	60.00
75	73.00	72.00	88	99	64.00
49	72.00	88.00	97	122	70.00
56	74.00	67.00	86	91	64.00
39	N/R	N/R	N/R	N/R	N/R
31	75.00	45.00	56	60	42.00
14	74.00	78.00	104	105	77.00
11	76.00	68.00	97	89	74.00
62	71.00	84.00	100	118	71.00
10	80.00	52.00	86	65	69.00
18	72.00	75.00	108	104	78.00
22	80.00	73.00	69	91	55.00
73	N/R	N/R	N/R	N/R	N/R
9	74.00	49.00	54	66	40.00
46	72.00	79.00	96	110	69.00
41	71.00	57.00	39	80	28.00
64	74.00	75.00	84	101	62.00
67	75.00	85.00	92	113	69.00

28	72.00	70.00	106	97	76.00
16	74.00	39.00	86	53	64.00
29	73.00	N/R	N/R	N/R	N/R
i.d.	**FEV1% predicted**	**FEV1% pre VF**	**%predicted post VF**	**% Predicted pre VF**	**FEV1% post VF**
23	72.00	73.00	60	101	43.00
30	76.00	59.00	97	78	74.00
4	77.00	44.00	69	57	53.00
53	74.00	46.00	86	62	64.00
63	73.00	24.00	30	33	22.00
66	76.00	84.00	92	111	70.00
1	23.00	N/R	42	N/R	31.00
35	77.00	82.00	95	106	73.00
72	72.00	28.00	40	39	29.00
68	73.00	50.00	79	68	58.00
37	75.00	63.00	115	84	86.00
12	76.00	51.00	51	67	39.00
69	73.00	68.00	108	93	79.00
70	80.00	35.00	52	44	42.00
34	75.00	77.00	103	103	77.00
36	75.00	76.00	103	101	77.00
65	N/R	N/R	N/R	N/R	N/R
33	79.00	95.00	116	120	92.00
42	82.00	83.00	98	101	80.00
8	71.00	81.00	113	114	80.00
17	78.00	87.00	100	112	78.00
19	77.00	84.00	108	109	83.00
45	79.00	82.00	95	104	75.00
50	74.00	80.00	124	108	92.00

i.d.	% difference	PEF pre VF	PEF	% predicted PEF pre VF	PEF post VF	% of predicted post VF
2	-6	79.00	N/R	67	252.00	44
6	-2	N/R	126.00	17	86.00	19
3	N/R	N/R	223.00	N/R	326.00	69
27	N/R	134.00	205.00	N/R	N/R	N/R
52	-3	201.00	147.00	31	89.00	22
61	N/R	173.00	179.00	N/R	N/R	N/R
44	-2	111.00	173.00	52	282.00	66
58	-7	493.00	224.00	30	165.00	37
77	5	204.00	75.00	46	166.00	37
21	-20	241.00	277.00	48	157.00	38
25	-15	545.00	56.00	32	302.00	67
51	-30	200.00	91.00	34	132.00	26
60	10	31.00	87.00	43	127.00	30
74	-4	159.00	205.00	29	56.00	15
76	-14	65.00	N/R	32	199.00	37
48	-49	56.00	107.00	113	477.00	110
5	1	111.00	190.00	53	129.00	30
13	-9	N/R	180.00	43	65.00	14
26	-29	362.00	180.00	24	62.00	20

i.d.	% difference	PEF pre VF	PEF	% predicted PEF pre VF	PEF post VF	% of predicted post VF
24	3	320.00	307.00	58	139.00	29
38	4	N/R	111.00	129	339.00	80
47	-6	246.00	133.00	15	54.00	14
59	-38	231.00	255.00	55	214.00	59
57	31	365.00	32.00	36	85.00	33
43	-8	N/R	46.00	11	28.00	10
15	3	127.00	59.00	28	133.00	42
20	28	48.00	89.00	46	43.00	13
54	N/R	212.00	N/R	53	176.00	45
55	-11	269.00	64.00	19	101.00	29
7	-11	39.00	40.00	N/R	N/R	N/R
40	-25	95.00	192.00	17	32.00	10
75	-5	48.00	495.00	33	88.00	27
49	N/R	552.00	N/R	37	91.00	30
56	-4	636.00	257.00	51	151.00	41
39	-1	168.00	49.00	N/R	N/R	N/R
31	8	150.00	355.00	40	190.00	43
14	-18	86.00		74	366.00	75
11	21	576.00	455.00	36	271.00	54
62	3	475.00	N/R	31	95.00	21
10	-22	413.00	N/R	26	207.00	36
18	N/R	426.00	444.00	67	460.00	97
22	-12	446.00	415.00	53	197.00	34
73	-10	453.00	516.00	N/R	N/R	N/R
9	-41	420.00	384.00	23	105.00	21
46	-17	543.00	435.00	56	169.00	39
41	-21	424.00	475.00	40	52.00	16
64	9	307.00	415.00	77	269.00	90
67	33	474.00	426.00	78	263.00	80
28	N/R	386.00	363.00	91	378.00	94
16	-41	254.00	280.00	10	29.00	9
29	19	316.00	342.00	N/R	N/R	N/R
23	12	390.00	344.00	15	30.00	10
30	24	N/R	321.00	33	137.00	36
4	-3	327.00	304.00	16	75.00	20
53	-19	372.00	N/R	14	84.00	24
63	N/R	446.00	489.00	19	70.00	15
66	-11	503.00	455.00	46	199.00	43
1	1	581.00	475.00	N/R	67.00	16
35	11	581.00	N/R	49	225.00	41
72	29	493.00	436.00	14	79.00	18
68	-16	335.00	300.00	12	32.00	10
37	15	328.00	401.00	8	16.00	3
12	8	316.00	292.00	19	49.00	10
69	0	314.00	385.00	44	228.00	53
70	2	368.00	344.00	9	51.00	9
34	N/R	476.00	464.00	111	416.00	93
36	-4	129.00	546.00	111	459.00	92
65	-3	446.00	320.00	N/R	N/R	N/R
33	-1	476.00	508.00	115	596.00	108

i.d.	% difference	PEF pre VF	PEF	% predicted PEF pre VF	PEF post VF	% of predicted post VF
42	-12	434.00	555.00	43	254.00	42
8	-1	446.00	498.00	63	138.00	52
17	-9	N/R	554.00	14	73.00	21
19	16	602.00	266.00	39	204.00	54
45		348.00	381.00	88	347.00	86
50		404.00	327.00	26	87.00	27

i.d.	% difference	Predicted MEF25-75	MEF25-75 pre VF	% of predicted pre VF	MEF25-75 post VF
2	-23	4.80	4.70	98	3.20
6	2	2.78	0.55	20	0.67
3	N/R	3.13	N/R	N/R	2.73
27	N/R	N/R	N/R	N/R	N/R
52	-9	2.50	0.90	36	0.73
61	N/R	N/R	N/R	N/R	N/R
44	8	2.52	2.30	91	2.61
58	7	3.02	0.94	31	0.97
77		2.97	0.57	19	0.61
21		2.25	2.06	91	1.38
25	-6	3.01	0.94	31	1.03
51	-10	3.43	1.75	51	109.00
60	32	2.34	1.11	47	0.40
74	-8	2.23	0.79	35	0.56
76	-13	3.75	1.60	43	1.46
48	-14	2.51	2.94	117	3.21
5	5	2.27	1.52	67	1.23
13	-3	2.83	1.43	50	0.30
26	-23	2.11	0.50	24	0.11
71	-29	2.46	0.80	33	0.65
24	-4	2.95	3.53	120	1.83
38	-5	2.61	4.63	178	3.68
47	-29	2.39	0.22	9	0.22
59	-48	2.67	1.46	55	1.57
57	-1	1.66	0.54	32	0.50
43	4	1.89	0.25	13	0.15
15	-3	2.28	0.85	37	1.45
20	-1	2.23	0.74	32	0.34
54	14	3.37	2.21	66	2.20
55	-33	2.36	0.47	20	0.47
7	-8	N/R	N/R	N/R	N/R
40	-7	2.27	0.35	16	0.17
75	-6	2.18	0.48	22	0.46
49	-7	1.91	0.65	34	0.33
56	-10	2.54	1.02	40	0.68
39	N/R	N/R	N/R	N/R	N/R
31	3	3.06	0.49	16	0.49

i.d.	% difference	Predicted MEF25-75	MEF25-75 pre VF	% of predicted pre VF	MEF25-75 post VF
14	1	3.23	2.20	68	2.38
11	18	3.51	1.59	45	1.25
62	-20	2.49	1.10	44	0.79
10	10	4.69	1.40	30	1.63
18	30	2.83	1.76	62	2.40
22	-18	4.69	2.86	61	1.79
73	N/R	N/R	N/R	N/R	N/R
9	-2	3.13	0.93	30	0.74
46	-18	2.48	2.23	90	1.59
41	-24	1.94	0.52	27	0.21
64	18	2.27	1.22	54	0.73
67	2	2.52	1.49	59	0.69
28	3	2.44	1.19	49	1.24
16	-1	2.28	0.13	5	0.15
29	N/R	2.08	N/R	N/R	N/R
23	-5	2.06	0.23	11	0.05
30	3	2.89	0.53	18	1.36
4	4	2.91	0.63	22	0.79
53	10	2.41	0.57	24	0.59
63	-4	2.92	0.60	20	0.73
66	-3	3.27	2.25	69	1.57
1	N/R	2.65	N/R	N/R	0.48
35	-8	3.88	2.50	64	1.62
72	4	2.56	0.26	10	0.32
68	-2	2.16	0.25	12	0.25
37	-5	3.31	0.35	10	0.24
12	-9	3.60	0.34	9	0.35
69	8	2.64	1.47	56	2.05
70	6	4.46	0.23	5	0.48
34	-18	3.06	4.32	141	4.25
36	-19	3.42	2.72	80	2.53
65	N/R	N/R	N/R	N/R	N/R
33	-7	4.28	5.81	136	5.55
42	-1	5.03	3.90	78	3.39
8	-6	1.68	1.71	102	1.61
17	7	2.94	0.43	15	0.31
19	15	2.90	1.43	49	2.96
45	-2	3.40	3.13	92	2.90
50	1	2.35	1.07	45	0.58

i.d.	% difference	Actual change in FEV1	Actual change inFVC	Actual change in FEV1%r	Actual change in PEF	Actual change in MEF25-75
2	-31	-0.93	0.26	-22.00	-132.00	-1.50
6	4	0.16	0.27	-1.00	7.00	0.12
3	N/R	N/R	N/R	N/R	N/R	N/R
27	N/R	N/R	N/R	N/R	N/R	N/R
52	-7	-0.36	-0.38	-2.00	-37.00	-0.17
61	N/R	N/R	N/R	N/R	N/R	N/R
44	13	-0.12	-0.10	-1.00	59.00	0.31
58	1	0.36	0.70	-5.00	31.00	0.03
77	2	0.07	0.17	-1.00	-39.00	0.04
21	-30	0.27	0.97	-23.00	-44.00	-0.68
25	3	0.45	0.56	8.00	155.00	0.09
51	-19	-0.36	0.61	-14.00	-41.00	107.25
60	-30	-0.38	-0.20	-11.00	-52.00	-0.71
74	-10	-0.58	-0.32	-22.00	-55.00	-0.23
76	-4	-0.29	-0.57	7.00	26.00	-0.14
48	11	0.25	0.51	-3.00	-16.00	0.27
5	-13	-0.01	0.41	-10.00	-95.00	-0.29
13	-39	-1.33	-0.64	-35.00	-139.00	-1.13
26	19	0.19	0.24	1.00	-13.00	-0.39
71	-6	0.11	0.37	-7.00	-19.00	-0.15
24	-58	-0.41	0.13	-21.00	-138.00	-1.70
38	-26	-0.40	-0.37	-2.00	-206.00	-0.95
47	0	0.09	0.13	2.00	-2.00	0.00
59	4	0.02	-0.07	3.00	14.00	0.11
57	-2	0.03	0.18	-4.00	-6.00	-0.04
43	-7	0.03	0.32	-28.00	-3.00	-0.10
15	27	0.03	-0.47	23.00	46.00	0.60
20	-17	-0.07	0.13	-6.00	-116.00	-0.40
54	-1	-0.04	-0.11	2.00	-29.00	-0.01
55	0	0.45	-0.04	21.00	36.00	0.00
7	N/R	N/R	N/R	N/R	N/R	N/R
40	-9	-0.06	0.01	-8.00	-24.00	-0.18
75	-1	-0.04	0.08	-8.00	-19.00	-0.02
49	-17	0.17	0.40	-18.00	-20.00	-0.32
56	-13	-0.48	-0.63	-3.00	-39.00	-0.34
39	N/R	N/R	N/R	N/R	N/R	N/R
31	0	-0.06	0.06	-3.00	10.00	0.00
14	6	0.16	0.24	-1.00	4.00	0.18
11	-9	-0.49	-0.91	6.00	91.00	-0.34
62	-8	-0.05	0.16	-13.00	-44.00	-0.31
10	5	0.20	-0.65	17.00	56.00	0.23
18	23	0.52	0.56	3.00	140.00	0.64
22	-23	-0.98	-0.11	-18.00	-110.00	-1.07
73	N/R	N/R	N/R	N/R	N/R	N/R
9	-6	-0.30	-0.12	-9.00	-6.00	-0.19
46	-26	-0.17	0.19	-10.00	-77.00	-0.64
41	-16	-0.81	-0.56	-29.00	-81.00	-0.31
64	-22	-0.14	0.28	-13.00	38.00	-0.49
67	-32	0.13	0.57	-16.00	8.00	-0.80
28	2	-0.07	-0.30	6.00	13.00	0.05

i.d.	% difference	Actual change in FEV1	Actual change inFVC	Actual change in FEV1%r	Actual change in PEF	Actual change in MEF25-75
16	2	0.04	-0.24	25.00	-3.00	0.02
29	N/R	N/R	N/R	N/R	N/R	N/R
23	-8	-0.16	-0.02	-30.00	-16.00	-0.18
30	29	0.30	-0.05	15.00	10.00	0.83
4	5	0.13	-0.08	9.00	16.00	0.16
53	0	0.18	-0.11	18.00	36.00	0.02
63	-1	-0.10	-0.03	-2.00	-19.00	0.13
66	-21	-0.27	0.13	-14.00	-13.00	-0.68
1	N/R	N/R	N/R	N/R	N/R	N/R
35	-22	-0.09	0.21	-9.00	-44.00	-0.88
72	2	0.09	0.18	1.00	15.00	0.06
68	-1	-0.06	-0.20	8.00	-7.00	0.00
37	-3	-0.24	-0.50	23.00	-24.00	-0.11
12	1	-0.45	-0.41	-12.00	-46.00	0.01
69	22	0.16	-0.17	11.00	36.00	0.58
70	6	-0.03	-0.39	7.00	3.00	0.25
34	-2	-0.18	-0.18	0.00	-79.00	-0.07
36	-6	-0.24	-0.36	1.00	-93.00	-0.19
65	N/R	N/R	N/R	N/R	N/R	N/R
33	-6	-0.01	0.10	-3.00	-40.00	-0.26
42	-9	-0.33	-0.27	-3.00	-3.00	-0.51
8	-6	-0.01	-0.35	-1.00	-30.00	-0.10
17	-5	0.09	0.14	-9.00	24.00	-0.12
19	53	1.17	1.43	-1.00	54.00	1.53
45	-7	0.04	0.46	-7.00	-8.00	-0.23
50	-30	0.06	-0.05	12.00	1.00	-0.49

N/R = not recorded,

Type of disorder: 1= acute stroke, 2 = sub acute stroke, 3= Parkinson's disease, 4 = Multiple Sclerosis, 5 = motor neurone disease, 6 = head injury

Smoker: G = given up, N=never smoked, C = current smoker

Snoring: N = non snorer, O= occasional snorer, F= frequent but not heavy snorer, H= heavy snorer, D = don't know

Figure F.01- Box and whisker plot demonstrating median % difference in oxygen saturation levels after swallowing by gender and disorder (stroke)

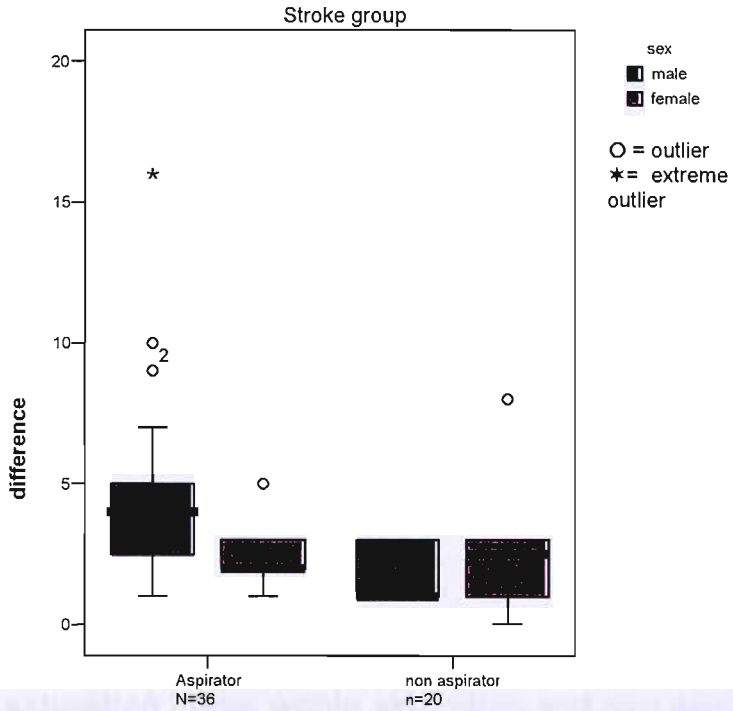


Figure F-02 Box and whisker plot demonstrating median % difference in oxygen saturation levels after swallowing by gender and disorder (neurology)

O = outlier
✶= extreme outlier

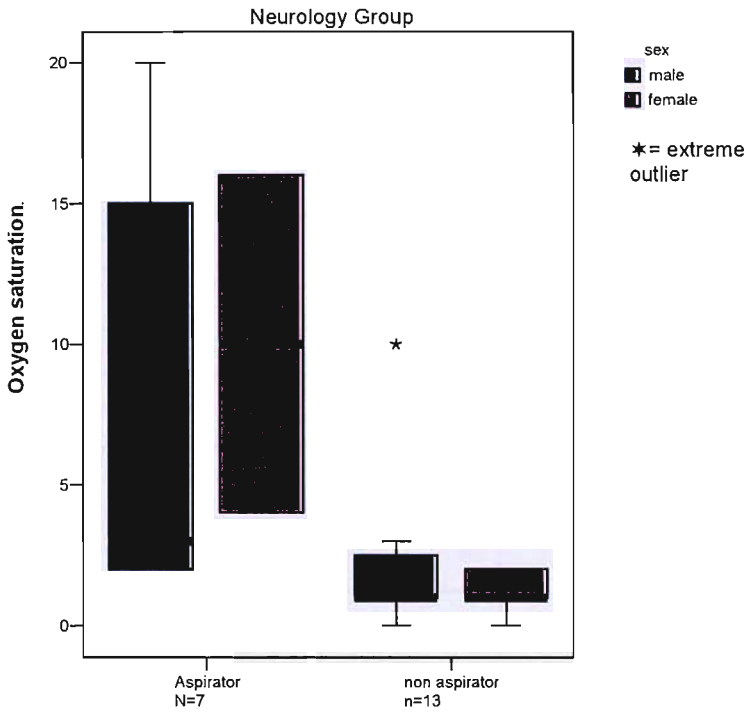


Table F-02 Mann-Whitney U tests comparing the differences in oxygen saturation levels within aspirating and non aspirating groups before and after swallowing and mean % difference by gender and disorder

Group	sex	Disorder	Paired Differences				z	Exact Sig.
			Mean	Std. Deviation	95% Confidence Interval of the Difference			
					Lower	Upper		
aspirator	male	Stroke N=20	4.61	3.38	3.15	6.07	-4.207	.000
		Neurology N=5	8.40	8.50	-2.16	18.96	-2.032	.042
	female	Stroke N=13	2.46	1.33	1.66	3.27	-3.208	.001
		Neurology N=2	10.00	8.49	-66.24	86.24	-1.342	.180
Non aspirator	male	Stroke N=10	1.60	.97	.91	2.29	-2.919	.004
		Neurology N=8	2.38	3.20	-.30	5.05	-2.410	.016
	female	Stroke N=10	3.10	2.77	1.12	5.08	-2.682	.007
		Neurology N=5	1.00	1.00	-.24	2.24	-1.633	.102

Table F-03 Independent t-tests for whole group. Comparing differences between aspirating and non aspirating subjects' oxygen saturation levels pre and post VF and the mean % difference

Aspirators vs non aspirators	t-test for Equality of Means					
	t	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
					Lower	Upper
PRE VF FVC	-1.13	.26	-.36	.32	-.98	.27
POST VF FVC	-.60	.55	-.19	.32	-.83	.45
PRE VF FEV_1	-1.24	.22	-.31	.25	-.82	.19
POST VF FEV_1	-1.44	.16	-.34	.24	-.82	.13
actual difference between pre and post VF FEV_1	-.67	.51	-.06	.09	-.24	.12
actual difference between pre and post VF FVC	1.0	.32	.10	.10	-.10	.30

Table F-04 Independent t-tests for stroke group. Comparing differences between aspirating and non aspirating subjects' oxygen saturation levels pre and post VF and the mean % difference

	t-test for Equality of Means					
Aspirators vs non aspirators	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
FVC PRE VF	-.62	47	.54	-.21	-.88	.46
FVC POST VF	-.03	48	.98	-.01	-.71	.69
FEV_1 PRE VF	-.05	47	.96	-.014	-.55	.52
FEV_1 POST VF	.09	48	.93	.021	-.48	.52
actual difference between pre and post VF FEV1	-.14	47	.89	-.015	-.24	.21
actual difference between pre and post VF FVC	1.22	47	.23	.14	-.094	.38

Table F-05 Paired t-tests for stroke group. Comparing differences within aspirating and non aspirating subjects' spirometry measurements pre and post VF

		Paired Differences					
		Mean	Std. Deviation	95% Confidence Interval of the Difference			
				Lower	Upper	t	Sig. (2-tailed)
Aspirator N=34	FVC	-.08	.40	-.23	.07	-1.14	.26
	FEV1	.10	.39	-.04	.24	1.47	.15
Non aspirator N=16	FVC	.06	.39	-.13	.25	.67	.52
	FEV1	.09	.38	-.10	.27	.99	.34

Table F-06 Mann-Whitney U tests for stroke group. Comparing differences within aspirating and non aspirating subjects' spirometry measurements pre and post VF

		Paired Differences					
		Mean	Std. Deviation	95% Confidence Interval of the Difference			
				Lower	Upper	z	Actual Sig.
Aspirator N=34	FEV 1%	6.06	12.82	1.36	10.77	-2.794	.005
	PEF	29.35	69.18	3.98	54.73	-2.412	.016
	MEF25-75	-3.21	19.32	-10.29	3.88	-2.899	.004
Non Aspirator N =16	FEV 1%	2.39	16.04	-5.59	10.36	-.566	.571
	PEF	-4.72	59.85	-34.48	25.04	-.589	.556
	MEF25-75	.12	.47	-.11	.36	-.880	.379

Table F-07 Independent t-tests for neurology group. Comparing differences between aspirating and non aspirating subjects' spirometry measurements pre and post VF and the mean % difference

	t-test for Equality of Means					
Aspirators vs non aspirators	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
FVC PRE VF	-.52	16	.612	-.44	-2.23	1.35
FVC POST VF	-.48	17	.639	-.38	-2.05	1.29
FEV_1 PRE VF	-1.46	16	.164	-.97	-2.39	.44
FEV_1 POST VF	-1.93	17	.070	-1.13	-2.36	.10
actual difference between pre and post VF FEV_1	-.78	16	.446	-.13	-.50	.23
actual difference between pre and post VF FVC	-.13	16	.895	-.03	-.52	.46

Table F-08 Paired t-tests for neurology group. Comparing differences within aspirating and non aspirating groups spirometry measurements pre and post VF

		Paired Differences					
		Mean	Std. Deviation	95% Confidence Interval of the Difference			
				Lower	Upper	t	Sig. (2-tailed)
Aspirator N=7	FVC	.035	.28	-.25	.32	.31	.767
	FEV_1	.11	.13	-.03	.25	2.09	.091
non aspirator n=11	FVC	.00	.52	-.33	.34	.028	.978
	FEV_1	-.02	.41	-.28	.24	-.19	.851

Table F-09 Mann-Whitney U tests for neurology group. Comparing differences within aspirating and non aspirating groups spirometry measurements pre and post VF

		Paired Differences					
		Mean	Std. Deviation	95% Confidence Interval of the Difference			
				Lower	Upper	z	Exact Sig.
Aspirator N=7	FEV_1%	-1.17	13.17	-14.98	12.65	.000	1.000
	PEF	15.33	19.52	-5.15	35.82	-1.472	.141
	MEF_{25-75}	.25	.43	-.20	.69	-.943	.345
non aspirator n=11	FEV_1%	.42	7.43	-4.30	5.14	-.400	.689
	PEF	15.08	44.36	-13.10	43.27	-1.024	.306
	MEF_{25-75}	-.03	.56	-.39	.32	-.748	.454

Table F-10 Kappa's coefficient for gender and disorder

Stroke	Male	k= .631	good agreement	Female	k = .073	poor agreement
Neurology	male	k=.562	moderate agreement	Female	k = .462	moderate agreement

Table F-11: Whole group - Collar size divided by size and gender:

	Collar size	Frequency	Percent %
Male	**Size 17 or above**	19	25
	Less than size 17	27	35
Female	**Size 16 or above**	6	8
	Less than size 16	24	32

Table F-12: Whole Group - Collar size divided by aspiration and gender:

		Collar size	Frequency	Percent %
Male	Aspirator	Size 17 or above	7	9
		Less than size 17	21	28
	Non Aspirator	Size 17 or above	12	16
		Less than size 17	6	8
Female	Aspirator	Size 16 or above	1	1
		Less than size 16	14	18
	Non Aspirator	Size 16 or above	5	7
		Less than size 16	10	13

Table F-13: Stroke Subjects: collar size distribution

	Collar Size	Frequency	Percent
Aspirator	Size 16 / 17 and above	6	11
	Less than size 16 / 17	30	54
Non Aspirator	Size 16 / 17 and above	9	16
	Less than size 16 / 17	11	19

Table F-14: Neurology Subjects – collar size distribution

		Frequency	Percent
Aspirator	Size 16 /17 and above	2	10
	Less than size 16 /17	5	25
Non Aspirator	Size 16 /17 and above	8	40
	Less than size 16 /17	5	25

Table F-15: Collar size by gender and disorder:

Disorder	Asp/ Non Aspirator	Sex	Collar Size	Frequency
Stroke	Aspirator	Male	Size 17 or above	5
			Less than size 17	18
		Female	Size 16 or above	1
			Less than size 16	12
	Non Aspirator	Male	Size 17 or above	6
			Less than size 17	4
		Female	Size 16 or above	3
			Less than size 16	7
Neurology	Aspirator	Male	Size 17 or above	2
			Less than size 17	3
		Female	Size 16 or above	0
			Less than size 16	2
	Non Aspirator	Male	Size 17 or above	6
			Less than size 17	2
		Female	Size 16 or above	2
			Less than size 16	3

Table F-16: Stroke Subjects: smoking distribution

		Frequency	Percent
Aspirator	Never smoked or gave up > 5yrs	32	57
	Smoker or gave up < 5yrs ago	4	5
Non Aspirator	Never smoked or gave up > 5yrs	15	27
	Smoker or gave up < 5yrs ago	5	9

Table F-17: Neurology Subjects – smoking distribution

		Frequency	Percent
Aspirator	Never smoked or gave up > 5yrs	5	25
	Smoker or gave up < 5yrs ago	2	10
Non Aspirator	Never smoked or gave up > 5yrs	8	40
	Smoker or gave up < 5yrs ago	5	25

F-18: Smoking by disorder and gender

Disorder	Asp/ Non Aspirator	Sex	Smoking history	Frequency
Stroke	Aspirator	Male	Never smoked or gave up > 5yrs	20
			Smoker or gave up < 5yrs ago	3
		Female	Never smoked or gave up > 5yrs	12
			Smoker or gave up < 5yrs ago	1
	Non Aspirator	Male	Never smoked or gave up > 5yrs	5
			Smoker or gave up < 5yrs ago	5
		Female	Never smoked or gave up > 5yrs	10
			Smoker or gave up < 5yrs ago	0
Neurology	Aspirator	Male	Never smoked or gave up > 5yrs	4
			Smoker or gave up < 5yrs ago	1
		Female	Never smoked or gave up > 5yrs	1
			Smoker or gave up < 5yrs ago	1
	Non Aspirator	Male	Never smoked or gave up > 5yrs	3
			Smoker or gave up < 5yrs ago	5
		Female	Never smoked or gave up > 5yrs	5
			Smoker or gave up < 5yrs ago	0

F-19: Stroke Subjects – cough to command

		Frequency	Percent
Aspirator	No	3	5
	Yes	33	59
Non Aspirator	No	0	0
	Yes	20	36

F-20: Neurological subjects – cough to command

		Frequency	Percent
Aspirator	No	0	0
	Yes	7	35
Non Aspirator	No	2	10
	Yes	11	55

F-21: Voluntary cough by disorder and sex

Disorder	Asp/ Non Aspirator	Sex	Cough to command	Frequency
Stroke	Aspirator	Male	No	2
			Yes	21
		Female	No	1
			Yes	12
	Non Aspirator	Male	No	0
			Yes	10
		Female	No	0
			Yes	10
Neurology	Aspirator	Male	No	0
			Yes	5
		Female	No	0
			Yes	2
	Non Aspirator	Male	No	1
			Yes	7
		Female	No	1
			Yes	4

F-22: Stroke Subjects – spontaneous cough

		Frequency	Percent
Aspirator	No	29	52
	Yes	7	13
Non Aspirator	No	3	5
	yes	17	30

F-23: Neurological Subjects – spontaneous cough

		Frequency	Percent
Aspirator	No	6	30
	Yes	1	1
Non Aspirator	No	3	15
	yes	10	50

F-24: Spontaneous cough by disorder and sex

Disorder	Asp/ Non Aspirator	Sex	Spontaneous Cough	Frequency
Stroke	Aspirator	Male	No	17
			Yes	6
		Female	No	12
			Yes	1
	Non Aspirator	Male	No	2
			Yes	8
		Female	No	1
			Yes	9
Neurology	Aspirator	Male	No	4
			Yes	1
		Female	No	2
			Yes	0
	Non Aspirator	Male	No	2
			Yes	6
		Female	No	1
			Yes	4

F-25: Stroke Subjects – snoring

		Frequency	Percent
Aspirator	Never or occasional snorer	15	27
	Snorer +don't know	21	38

Non Aspirator	Never or occasional snorer	14	25
	Snorer +don't know	6	11

F-26: Neurology Subjects – snoring

		Frequency	Percent
Aspirator	Never or occasional snorer	4	20
	Snorer +don't know	3	15
Non Aspirator	Never or occasional snorer	6	30
	Snorer +don't know	7	35

F-27: Snoring by disorder and gender

Disorder	Asp/ Non Aspirator	Sex	Snoring history	Frequency
Stroke	Aspirator	Male	Never or occasional snorer	8
			Snorer +don't know	15
		Female	Never or occasional snorer	7
			Snorer +don't know	6
	Non Aspirator	Male	Never or occasional snorer	5
			Snorer +don't know	5
		Female	Never or occasional snorer	9
			Snorer +don't know	1
Neurology	Aspirator	Male	Never or occasional snorer	2
			Snorer +don't know	3
		Female	Never or occasional snorer	2
			Snorer +don't know	0
	Non Aspirator	Male	Never or occasional snorer	4
			Snorer +don't know	4
		Female	Never or occasional snorer	2
			Snorer +don't know	3

F-28 Logistic regression

		B	S.E.	Sig.	Exp(B)
Step 3(c)	Collar size(1)	1.701	.615	**.006**	5.480
	snoring(1)	1.173	.601	**.051**	3.232
	Fall in oxygen saturation(1)	-2.422	.664	**.000**	.089
	Constant	.221	.614	.719	1.247

F-29 Statistical Significance of k:

Value of k	**Strength of agreement**
< 0.20	Poor
0.21 – 0.40	Fair
0.41 -0.60	Moderate
0.61 – 0.80	Good
0.81 – 1.00	Very Good

Landis & Koch 1977

11.00 CHAPTER ELEVEN: References

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