Laboratory Test of Automated Easy-Use Portable Suction System and Its Implications in Alleviating After-Stroke Aspiration Pneumonia

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Abstract
The prevalence of stroke causes many social and economic problems. After stroke aspiration pneumonia (ASAP) is a common complication and occurs after having a stroke due to dysphagia. Taking care of oral conditions has been regarded as an efficient way to prevent the ASAP. In this case, an automated easy-use portable suction system (EPSS) was developed. Besides, laboratory tests were carried out to prove the feasibility of this system. Measuring the time needed to extract 100g stimulant and the mass of simulated sputum suctioned for 5 seconds in the beaker and an analogy model evaluates the efficiency of suctioning with different catheters and various concentrations (from 0 to 1.75%). The effectiveness of suctioning with the analogy model with different positions was also investigated. Results: The 4mm catheter is the most appropriate one used for EPSS to extract sputum. The time taken for EPSS is longer when suctioning thicker stimulants. Last but not least, the automation of the EPSS was achieved by writing the program to control the relay. Automated EPSS may provide a new treatment for stroke patients to prevent the ASAP.

Keywords
Sputum suctioning; Automated portable suction machine; Stroke; After-stroke aspiration pneumonia

Introduction

Recent studies show that Stroke remains the second-leading cause of death and the third-leading cause of death and disability combined (Valery et al., 2022). 16-33% of patients got pneumonia after having a stroke and suffer from a high possibility of death and readmission (Teramoto, 2009). The word after-stroke aspiration pneumonia (ASAP) describes the situation that stroke patients who gain pneumonia have a high incidence of aspiration. Pneumonia is classified into micro-aspiration pneumonia and macro-aspiration pneumonia by different causes (Inui et al., 2017; Koichiro, 2011). Fortunately, scientists rigorously studied pharmacological and non-pharmacological interventions and

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treatments to prevent aspiration pneumonia such as antibiotics, swallowing rehabilitation, and oral/nasal suctioning.

Oral care is an efficient way to prevent aspiration pneumonia through improving oral hygiene and eating function training which will significantly reduce the possibility of both macro and micro aspiration (Koichiro, 2011). Suction is a typical method to help improve oral conditions. Doctors adopt this procedure for patients who have difficulty in phlegm removal in order to reduce the incidence of aspiration and asphyxia due to airway blockage by phlegm (Chang et al., 2012). Stroke patients with dysphagia have a great possibility of aspiration which leads to pneumonia because of the pathogenic bacteria in the sputum (Teramoto, 2009). Most stroke patients develop a huge amount of copious sections that will exacerbate symptoms and cause severe consequences like receiving a tracheotomy that will influence the quality of social life afterwards (Sung et al., 2012). Current oral suction machines used in the hospital are manufactured for patients who get tracheotomy instead of stroke patients. Oral suction also requires training because of the complexity of the procedure. But family members of acute stroke patients usually have limited experience in post-stroke caring and have not realized the importance of oral hygiene for patients. As a result, they have less possibility of receiving oral suction before as a preventative measure. In order to reduce the risk of getting such pneumonia, passive suction to remove the sputum is necessary. There is an urgent need for a portable suction system to deal with this situation.

The present study is based on the idea that developing an automated portable system could help reduce the risk of pneumonia by extracting sputum regularly and can be operated by post-stroke family members conveniently. The experiments will be carried out to find the optimal sputum viscosity and the catheter diameter for EPSS. Then use the human analogy model to simulate the different positions patients are at to find the optimal position for stroke patients while suctioning by analyzing the suctioning efficiency. With these experiments as independent variables and the incidences of getting post-stroke aspiration pneumonia as variables, the study discusses the EPSS's efficiency in reducing the risk of aspiration pneumonia.

Background and Motivation: Stroke

Stroke is a syndrome of rapidly developing clinical signs of focal disturbance of cerebral function, with symptoms lasting 24 hours or longer or leading to death, with no apparent cause other than a vascular origin. (Wolfe, 2000)It remains the second-leading cause of death and the third-leading cause of death and disability combined measured by disability-adjusted life-years lost (DALYs). According to World Stroke Organization (WSO), humans have a greater probability of getting strokes nowadays. From 1990 to 2019, the incidence of strokes increased by 102.0%, the mortality rate increased by 43.0% and DALYs increased by 143.0%. (Valery et al., 2022) Especially in the low-middle income countries, people have a greater possibility of getting a stroke and have a higher death rate and DALYs due to lack of access to medical resources. (Valery et al., 2022) Stroke also raises heavy economic burdens on the patients' families as the treatment and rehabilitation procedure require a large amount of money. However, sometimes they may receive unexpected and undesired results like disability or death.

Additionally, post-stroke patients and their families encounter a series of significant problems. Dependency in activities in daily living(ADL), depression, central post-stroke pain(CPSP), and motor dysfunction are all regarded as the factors related to low QOL temporarily. Poor economic status and unemployment caused by stroke have long-term implications for QOL. (Choi-Kwon et al., 2006)

According to statistics from practice-based and population-based studies, over 30% of post-stroke patients will suffer from depression lasting several weeks to several months, sometimes even years. They will have persistent low moods or loss of interest in most activities for at least two weeks, with weight changes, altered sleep patterns, lack of energy, poor concentration, agitation, reduced self-esteem, and suicidal ideas or plan. People who have severe strokes or lesions that destroy the serotonin or norepinephrine transmitting pathways have a higher possibility of getting depression because of the difficulty of accepting the immense differences between the life before and after stroke affected by disability, aphasia and physical pain, etc. Other factors like gender, age, and lack of social support also contribute to the likelihood of depression. Moreover, depression will lead to poorer functional outcomes, increasing chances of mortality, and longer recovery time than expected for post-stroke patients. The caregivers of patients also tend to develop depression themselves as they take heavy burdens when taking care of temperamental patients. (Williams, 2005)
CPSP is a form of neuropathic pain caused by damage or dysfunction within the central nervous system such as disabling chronic pain and sensory abnormalities. Spontaneous pain or pain evoked by movement like allodynia is born constantly by patients who have the lesion associated with sensory such as thermal sensations. (Flaster et al., 2013) The resulting sensation disorder and "continuous, annoying pain" drastically reduce the QOL of post-stroke patients. They cannot sense the temperature correctly while it is a simple but vital ability for human beings to have and have enormous potential risks of injury by sensation disorder.

The disablement and motor dysfunction caused by stroke raise high dependency on ADL and significantly influence the social status and the career prospects of patients. According to the research done by Haghgoo et al. (2013), the rehabilitation process is tough for every post-stroke patient and their family. Firstly, the recovery process generally lasts for years. It is almost impossible to recover to the original physical state because of the existing damage in the brain. Moreover, retaking the abilities and skills owned before strokes such as walking, swallowing, and speaking fluently seem easy but require professional assistance and extra rehabilitation machines that are extremely expensive. Patients peculiarly in low-income areas cannot afford those medical resources and choose to accept current situations and live with disabilities. While developed countries have mature insurance systems and generous social welfare that can reduce the strain on patients, stroke survivors in developing countries often face serious situations such as unemployment and discrimination. As a result, high expenses for treatment and rehabilitation and low or even no income for survivors gradually lead to bankruptcy and losing their social advantages and status. Then, they will have low living standards and be trapped in this vicious circle.

In conclusion, more people nowadays get stroke which has a high mortality rate and leads to severe consequences and problems that influence the QOL. The exertion made to rehabilitation for living is a long process for stroke patients that requires countless care and professional knowledge from families and medical workers. Sufficient finance is needed as well. In this case, complications such as ASAP can be detected and solved in time and efficiently by taking preventative measurements and pharmacological or non-pharmacological treatments. As a result, patients can survive and maintain generally similar QOL compared to the one before having a stroke.

After Stroke Aspiration Pneumonia

Aspiration pneumonia is known as a common complication after strokes (Feng et al., 2019). 16-33% of patients got pneumonia after having a stroke and suffer from a high possibility of death and readmission. Clinically and chronologically, ASAP categorizes into two types of pneumonia by time, i.e. acute-onset post-stroke pneumonia develops within one month of stroke; chronic-onset post-stroke pneumonia occurs after one month of stroke (Teramoto, 2009).

After patients initially get a stroke, incidences of swallowing and cough dysfunction due to neurological deficits are noticeable. Despite no apparent aspiration found by nurses or doctors, the evident dysphagia often leads to macro-aspiration while patients swallow during a meal or apply nasogastric feeding tubes. Over one month after the stroke, the destruction of the neurological system is in remission. But the aspiration still bechances particularly in the types of silent aspiration or micro-aspiration such as unnoticed nasal, throat and secretions due to swallowing dysfunction (Teramoto, 2009).

One assumption pointing out the association between macro-aspiration and pneumonia is that illness may result from the change in the balance of lung microbiota determined by the amount of immigration and elimination of bacteria. Aspiration is the procedure of inhaling oropharyngeal or gastric contents into the larynx and lower respiratory tract (Cavallazzi et al., 2009). Aspiration is an ordinary event for both healthy people and patients in our daily life. An aspiration incidence in patients with abnormal swallowing function will break the elimination-immigration system because of an overwhelming amount of substance. Thus, a lung infection appears (Mandell & Niederman, 2019).

The word dysphagia depicts the disruption of bolus flow through the mouth and pharynx and is prevalent after stroke with an incidence rate of 20-78% (Singh, 2006). Substance p theory explains the reasons for post-stroke dysphagia. Cerebral damages, especially bilateral or multiple infractions decrease dopamine produced in the corpus nigrostriatal (Sasaki et al. 1997). The reduction of dopamine restrains the expression of substance p at the vagal and glossopharyngeal nerves. Controlling capsizing and angiotensin-converting enzyme (ACE) inhibitors can alleviate this situation (Teramoto, 2009). As a result, the decline of substance p may raise the issue of abnormal swallowing function (Sasaki et al. 1997) and is associated with the risk of pneumonia (Teramoto & Ouchi, 1999).

Around 300,000-600,000 people in the USA get swallowing dysfunction due to neurological deficits (Carnaby-Mann, 2007). Most patients will spontaneously recover from the swallowing issue, but an impressive amount of people will struggle with this illness at six months (Cohen et al., 2016). Moreover, the investigation made by Feng et al. shows an apparent relationship between dysphagia and aspiration pneumonia. Patients with dysphagia had a higher probability of pneumonia than those without dysphagia and demonstrated a 3 to 11-fold increase in the potential risk of having pneumonia within five years (Feng et al., 2019). Although there's no direct evidence to prove the causal relationship between dysphagia and chest infection (Hammond & Goldstein, 2006), dysphagia induces a three-fold increased mortality rate (Singh, 2006). The death of dysphagic stroke patients lies between 27%-37% of total stroke patients (Smithard et al.,, 1996). The explanation above exhibits the grievous effects of dysphagia and indicates the importance for nurses and doctors to take dysphagia seriously and monitor the swallowing function of every stroke patient in the hospital.

There are measurements performed like position concerning (Palazzo et al.,2016), tracheotomy and use of antibiotics to deal with aspired bacteria; medicines that improve the cough reflex sensitivity and so on to prevent ASAP from post-stroke patients with dysphagia. However, the effectiveness of completely solving this issue is doubted with apparent drawbacks. For example, an endotracheal tube can impede macro-aspiration but offers little help to prevent micro-aspiration of pharyngeal or gastric contents (Armstrong & Mosher, 2011). The trauma destroys the whole immune system of patients and not only causes countless risks and complications but also interferes with their QOL (Cipriano et al., 2015).

Oral care and oral suction machine

Oral care can efficiently prevent aspiration pneumonia by improving oral hygiene and swallowing function training. Oral secretion such as saliva varies with its viscosity from watery to tenacious and secretion coming from the throat, lungs, or nose is a factor concerned when tackling oral hygiene. Sialorrhoea is a term used to describe excessive serous saliva in the mouth which is resulted from facial-bulbar weakness in stroke patients. Saliva may pool at the back of the throat, causing coughing and a higher risk of aspiration (Shah, 2005). Increased dental plaque formation and decreased buffering and antimicrobial capacity of saliva in the case of poor oral hygiene contribute to the increased numbers of pathogens shed in the saliva (Yoon & Steele, 2007). The evidence demonstrated by Edish E et al. (2002) illustrates the association between the secretion in the pharynx and aspiration in patients with dysphagia. They will encounter a higher possibility of being predisposed to aspirate pathogenic bacteria-laden saliva or oropharyngeal secretion from the oral cavity to the lower airway by poor oral hygiene. As a result, it is plausible that adequate clearance of oral secretion by passive suction may be of value in reducing the oropharyngeal colonization and the chance of infection. Moreover, oral suction for post-stroke patients should be considered carefully.

However, most of the previous studies focus on the effectiveness of oral suction in dealing with ventilation-associated pneumonia (VAP) for patients in ICU specifically. A firm body of data confirms the causal relationship between oropharyngeal colonization and VAP (Bonten et al., 1996; Garrouste-Orgeas et al., 1997). The pilot study done by Hui-Hwa Tsai et al. (2008) indicates that intermittent suction of oral secretions before each positional change might significantly reduce the possibility of VAP. The results demonstrate that patients without oral suction had a 4fold higher chance of having pneumonia compared with patients operating oral suction. Though only a little research on the effectiveness of oral suction on the ASAP has been carried out, the mechanism of forming ASAP mentioned above is similar to developing VAP because two kinds of pneumonia are both raised by swallowing bacteria-laden saliva. In conclusion, developing an oral suction machine for post-stroke patients should be considered as a preventative measurement of PASP.

The present oral suction machines have been categorized into two types of devices: the machines applied in hospitals and the portable suction machines used at home for patients with dysphagia. However, current oral suction machines used in the hospital are mainly designed for patients who get tracheotomy instead of stroke patients. Moreover, even if stroke patients can access oral suction, the frequency of suction is expected to be low. Firstly, there has been no direct evidence to suggest the link between aspiration pneumonia and oral suction, so doctors and nurses will not take this measurement seriously. Secondly, the complexity of the suction procedure and limited post-stroke caring experience of patients' families prevent the post-stroke patients accept oral suction to a great extent. As a result, suction is rare for stroke patients. Even though this procedure can extract the saliva, especially is pooled at the throat to improve the oral condition and reduce the incidence of aspiration. Meanwhile, this situation also strengthens the significance of user-friendly sputum suction machines / oral care by patients' families.

Therefore, an easy-use portable suction system (EPSS) is developed to provide stroke patients with a chance to access oral suction. The present study looks into the viscosity range of sputum and the optimal radius of the catheter for EPSS. Moreover, the feasibility of sputum suctioning at oral as a measurement to improve the oral condition and the best position for oral suction are also investigated in a human analogy model.

Materials and Methods: Easy-Use Portable Suctioning System (EPSS)

The EPSS consists of a mini-pump (TY-C3-12W, Tengyue, Guangdong, China), a suction bottle (volume 500ml), connecting tube, and suction catheters (Jiangyang, Jiangsu, China), and a relay (4 road best up, Shidai Huaxin, Shenzhen, China). The mini-pump exerts 80Kpa negative pressure. The power is 12W when connecting to a 12V power supply. All suction catheters tested are approximately 440mm long and have three holes at the end of the tube. The detailed information on the three types of catheters is shown below (Table 1). The tubes used to connect the mini-pump, suction bottle, and suction catheters are made up from silicone with an inner diameter of 7mm and an outer diameter of 12 mm.

Table 1. Detailed information of the catheters with different diameters

Outer Diameter/ mm	Inner diameter / mm	Side holes diameter/mm	Distance between side holes/mm
2	1	3	8
4	2	5	6
5.33	3	7	4

Simulated Mucus/Sputum

The simulated mucus/ sputum is made of polyethylene oxide coagulant (Sumltomo Selka Chemicals, Tokyo, Japan). The chemical is water-soluble and the molecular weight is around 8,000,000. The simulated mucus/sputum was prepared by adding the coagulant to 95 °C water quickly and continuing to stir it for 2 hours to ensure that the solute completely dissolves in the water. Diverse viscosity solutions are manufactured by adding different amounts of coagulant to the solvent from 0.375% to 1.675% and have similar properties compared to the sputum/mucus in the oral.

Suctioning Tests with a Beaker

Water is the control group. Three kinds of catheters are investigated by extracting varying concentrations of simulated sputum.100g liquid pours into the 300mL beaker.

Attach the bottle and the 2mm catheter with connecting tube and place the 2mm catheter naturally in the beaker. Turn on the machine for 5s. Calculate the weight of extracted simulated sputum by subtracting the device's mass before and after suctioning. Then the time needed to suction all of the solutions is recorded. The same procedure is repeated for higher concentrations of sputum until the viscosity of the sputum is thick enough that the catheter cannot extract any of it. Redo the experiment by replacing the 2mm catheter with a 4mm and 5.33mm catheter under the same conditions.

Additionally, repeat the experiment by measuring the mass of 0.75% stimulant extracted with three catheters three times and calculate the average of the measurements and the standard deviation of the data. The reason for selecting a 0.75% stimulant to run this test is that this solution has a viscosity similar to actual human sputum and to obtain more accurate results.

Suctioning Tests with a Human Analogy Model

The human oral analogy model injected with 10mL simulated sputum (concentration of 0.5%) is applied to imitate the situation when post-stroke patients have the symptom of Sialorrhoea. Due to the 2mm catheter barely functioning in 0.75% stimulant, 0.5% is used instead to obtain more apparent experiment results. The reason of not choosing 0.75% stimulants is Put the 2mm catheter into the model and adjust the model in the position of "0degree, perpendicular". Turn on the machine for 10s and note the masses of the model before and after the suction. Calculate the weight of extracting sputum as the subtraction between these two masses. Repeat the experiment with 4mm and 5.33mm diameter catheters and record the mass differences. Then the position of the oral model is adjusted and carry out the same procedure. Different postures are clarified below (Figure 1). Next, replace the 2mm with the other two catheters and repeat the experiment. Record all the data in detail.

90 degrees	45 degrees parallel	45 degrees perpendicular	0 degree parallel	0 degree perpendicular

Figure 1. The positions of human analogy model placed

Statistical Analysis

The one-way analysis of variance (ANOVA) statistical analysis (n = 3, α = 0.05) was carried out using R studio version 1.1.453. Statistically, significant ANOVA results were then tested with Tukey's HSD tests for post-hoc pairwise comparisons.

Results: Beaker Experiments

The tests investigate the catheters with different diameters and ranges of sputum viscosity on the suction effectiveness. As shown in Table 2 and Figure 2 below, the time needed to extract 100g of simulated sputum is shorter with a thicker tube when sputum concentration remains constant. Moreover, the experiment reveals that the suction time increases with higher viscosity, suggesting a decline in the suction rate for the same diameter catheters. Most importantly, larger diameter catheters cover a scope viscosity range to extract more simulated mucus. The 2mm catheter can barely suck up any simulated sputum beyond 1% concentration. The working concentration range for a 4mm catheter is up to 1.375%. The 5.33mm catheter can extract the whole setting range of simulated mucus concentrations.

Table 2. Time spent to extract 100g of simulated sputum from the beaker

		time spent/s		
Diameter of catheters		2mm	4mm	5.33mm
Concentration of simulated sputum g/dm3	0%	55	15	9
	0.375%	404	58	11
	0.5%	986	119	18
	0.625%	1,139	190	23
	0.75%	1,596	205	41
	0.875%	1,852	286	33
	1%	3,193	240	60
	1.125%	7,843	1,515	115
	1.25%	/	1,890	129
	1.375%	/	3,532	159
	1.5%	/	/	191
	1.625%	/	/	319
	1.75%	/	/	392

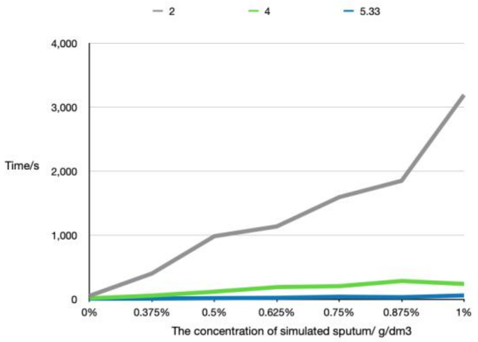

Figure 2. Time spent to extract 100g of various concentrations of simulated sputum by 2mm, 4mm, 5.33 mm catheters

Then, the tests are conducted to study the working efficiency of EPSS when the suction time remains at 5 seconds. Figure 3 and Table 3 show the 2mm catheter's minimal suction rate illustrated by mass suctioned when using various catheters. It extracts viscous liquid scarcely, especially with concentrations of solutions higher than 1%. A 5.33mm catheters have the highest efficiency among the three types of catheters. It is worth noticing that Figure 3 exhibits the difference between the stimulant mass extracted between 4mm and 5.33mm catheters is reduced when the concentration of liquid increases. Additionally, the mass of simulated sputum that the catheters extract gradually decreases when the sputum becomes thicker in the experiment.

Table 3. Mass of simulated sputum suctioned from the beaker for 5 seconds

		Mass /g		
Diameter of catheters		2mm	4mm	5.33mm
Concentration of simulated sputum g/dm3	0%	3.9	28.5	73.9
	0.375%	2.9	16.5	70.0
	0.5%	1.4	11.3	32.8
	0.625%	0.8	10.8	23.5
	0.75%	0.2	8.7	11.5
	0.875%	0.13	2.4	9.5
	1%	0.08	1.3	4.3
	1.125%	0.02	1.05	1.58
	1.25%	0.01	0.83	1.42
	1.375%	/	0.62	1.36
	1.5%	/	/	0.56
	1.625%	/	/	0.29

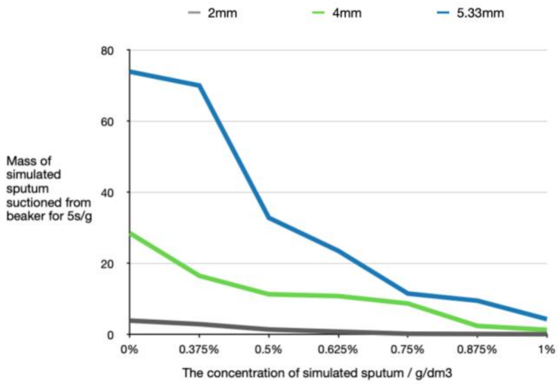

Figure 3. Mass of various concentration of simulated sputum suctioned from the beaker for 5 seconds by 2mm, 4mm, and 5.33mm catheters

In addition, the results of the experiment repeated with 0.75% stimulant are shown below (Figure 4). The differences between mass suctioned by three catheters are all significant and the difference between the 4mm and 5mm ($p=0.0003$) are relatively smaller than the 2mm and 4mm group ($p<0.0001$) and 2mm and 5.33mm group ($p<0.0001$).

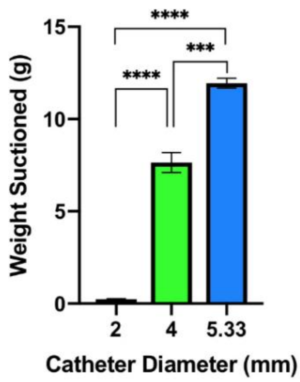

Figure 4. Mass of 0.75 concentrated simulated sputum suctioned from the beaker for 5 seconds by 2mm, 4mm, 5.33 mm catheters

Suction Test with the Human Analogy Model

The effectiveness of suction for EPSS with different positions that analogy model placing is tested by measuring the mass of stimulant suctioned before and after 5 seconds of suction. Table 4 and Figure 5 below demonstrate the general trend resulting from catheters with different diameters. It is distinct that the 4mm diameter tube extracts the uppermost amount of liquid from the analogy model while the 5.33mm catheter roughly is the most ineffective in suctioning compared with other catheters. The position model placing also raises some effects on suction efficiency. The rate of suctioning reaches maximum when the prototype is placed as "0 degree perpendicular" and the position in which the incline angle between the back of the model and floor is 90 degrees leads to the least efficiency in suctioning.

Table 4. Weight of simulated sputum suctioned from the human analogue model for 5 seconds

		mass suction/g		
Diameter of catheters		2mm	4mm	5.33mm
Position	90°	0.16	0.22	0.03
	45° parallel	0.27	0.29	0.15
	45°perpendicular	0.44	0.54	0.25
	0°parallel	0.08	0.40	0.31
	0°perpendicular	0.56	0.66	0.30

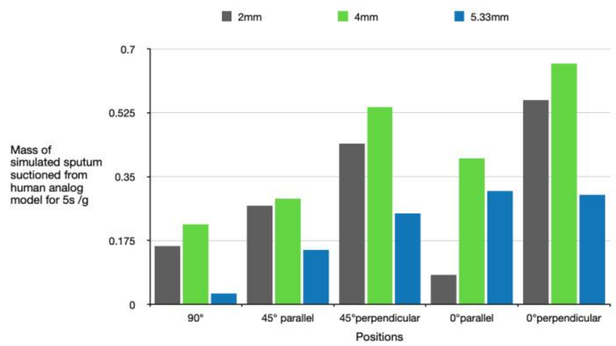

Figure 5. Mass of 0.5% simulated sputum suctioned from human analogue model for 5 seconds with various positions model placed

The Automation

The EPSS also includes the design of automation. The system can run with a specific time setting such as suction for 5 seconds every 10 minutes that can adjust according to the practical situation. The automation is achieved through a computer-controlled relay. The program shown below (Figure 6) plays the role of administrating the relay and setting working times.

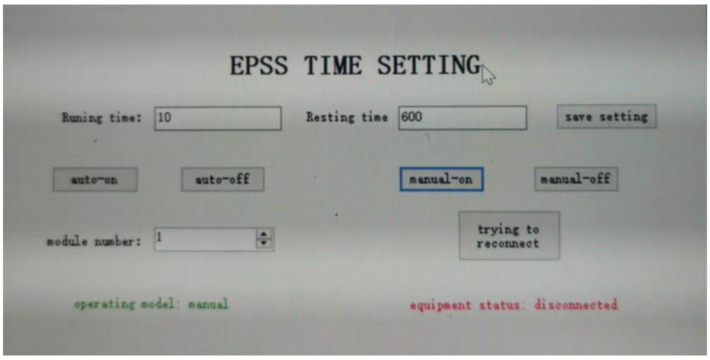

Figure 6. The interface of the programming shown on the computer

Discussion

The core study results are as follows:

-The EPSS can suction liquid similar to human sputum.

-After considering the parameters: the time required for suctioning 100g stimulant, the range of the consistency of simulated sputum extracted and the mass of viscous solution suctioned by catheter within 5 seconds, the 5.33mm catheter suggests to be more efficient in suctioning simulated sputum than 2mm and 4mm catheters in beaker experiment.

-The difference in stimulant mass suction between 4mm and 5.33mm catheters gradually decreases when the solution becomes thicker.

-The more viscous the solution is, the lower the suction efficiency EPSS has.

-The posture of the human analogy model plays a role in varying the mass extracted by the EPSS. The system will achieve its highest productivity when the analogy model is placed “perpendicular 0 degrees”.

-The 4mm catheter works more effectively in the human analogy model than the other catheters (2mm, 5.33mm) as it collects more stimulants within 5 seconds.

The Relation between the Beaker and Human Analogy Experiment

The study performs both experiments. The beaker experiment is planned to investigate the feasibility of EPSS and whether the system will run successfully and suction the sputum. The optimal viscosity range of stimulant and catheter can also be obtained in this experiment. Speaking of the human analogy experiment, it stimulates the actual physiological situation when EPSS is applied in human oral. The position experiment is designed to discover the first-rank posture patients have when using EPSS. In conclusion, all tests are used to find the best way of utilizing this suction machine.

Comparison of Catheters with Different Radius

The catheter is used to extract the sputum from oral. The previous beaker experiment certifies that the suction efficiency for a 5.33mm catheter is the highest through several parameters (mass extract within 5 seconds, consistency range, and the time required for suctioning 100g solution). The experiment did not try any thicker solutions higher than 1.625% concentration because the more viscous simulated solution has barely any similar properties compared with real sputum. (Shah et al., 2005) A higher amount of simulated sputum extracted by 5.33mm catheters may be due to the inner area of 5.33mm catheters being 55.6% and 88.9% larger than those of 2mm and 4mm separately. Even though the force exerted at the end of the tube with the 2mm diameter is expected to be the highest, the reducing size of the suction channel seems to contribute more to the effect of diminishing the suction efficiency.

The tests of analyzing the mass suctioned within 5 seconds in both beaker and human analogy model experiments are essential as they imitate the working procedure of EPSS in actual physiological conditions. However, collected mucus stimulants of concentration higher than 0.75% decreased substantially. The 0.75% to 1% stimulants are similar to human airway secretions which have high viscosity and viscoelasticity and are less likely to spread. (Shah et al., 2005) Moreover, the 5.33mm catheter extracts the lowest amount of mucus stimulant in a human analogy model experiment compared with other tubes due to the catheter's conformity in oral ergonomics. (Valery et al., 2022) These testing results reveal the little practical applicability of the 5.33mm catheter to patients.

Considering the 2mm catheter, the effectiveness of suctioning stimulant is suggested to be the lowest through assessing various parameters: the minimum scope of viscosity, less mass of simulated sputum extracted for 5 seconds in beaker experiment with all ranges of viscosities. Moreover, the performance of the 2mm catheter is relatively better than the 5.33mm catheter in the human analogy experiment. However, the tiny amount of mass suction indicates the extremely low suction rate and inefficiency of the 2mm catheter peculiarly at "0degree parallel" clarifies the inappropriateness of applying the 2mm catheter to patients.

As a result, the 4mm catheter is more suitable for patients who need suctioning. Despite this catheter does not have that outstanding performance in the beaker experiment as it has a smaller scope of bearable consistency range than the 5.33mm catheter, the gap between the suction rate of 5.33mm and 4mm catheters for 0.75% to 1% concentration simulated sputum which has a similar property to human secretion is relatively negligible. This catheter performs the best capability in the human analogy model experiment as well.

Importance: Relation between EPSS and Pneumonia

Oral functions are mostly suppressed by a depressed consciousness and disablement of swallowing function for stroke patients. So the secretion of saliva will be mixed with the residue in the oral epithelium to form a sticky paste that adheres to the oral cavity membranes and teeth, leading to silent aspiration of microorganisms (Koichiro, 2011). The procedure of suction is necessary for stroke patients to reduce the possibility of developing aspiration by eliminating the saliva and secretion. The human analogy model experiment has verified the exploitativeness of EPSS in practical physiological conditions as the right amount of simulated sputum can be extracted by the 4mm catheter from the oral in the trial. Therefore, EPSS should be regarded as a successful, effective measurement of oral suction. Oral care done by adequate clearance of oral secretion through passive suction is proved to be valid in reducing oropharyngeal colonization and the chance of aspiration pneumonia in the previous session. As a result, the application of EPSS to stroke patients may reduce the possibility of getting pneumonia.

The Automation

The achievement of automation will reduce the possibility of over-suctioning and damaging the soft tissue in the mouth. The frequency of suction procedures patients accept in the hospital is expected to be low due to the reasons already mentioned before (lack of professional knowledge and lack of medical staff). So the program allows less constant attention and time required for patients' families to spend on patients when using EPSS compared with other suction machines. Thus, the occurrence of EPSS brings higher feasibility for stroke patients to have oral suction.

Limitations and Future Study

However, the EPSS does face some problems that cannot tackle immediately.

Ethical Consideration

The EPSS is still a preliminary product without any certification thus the unknown risks of EPSS are undefined. So it is impossible to try this system on real patients at the present stage. The actual effectiveness and feasibility of EPSS in improving oral conditions are predictable through the trials done in the oral model. However, the effectiveness of the machine is not ensured unless more research is carried out on patients. Moreover, the limitations and drawbacks of EPSS such as malaise when applying EPSS for a long time are uncertain to patients. So advanced experiments should be held when EPSS ameliorates in the future. The actual effectiveness of EPSS on stroke patients is then can be inspected.

Moisture Concerning

The retaining of oral humidity which has been assumed to be an indicator of assessing oral hygiene is essential for stroke patients as proper moisture in the cavity will prevent the invasion of the pharynx by bacteria and deter the chance of getting silent aspiration and pneumonia (Takeyasu et al., 2014). Even though the EPSS in the previous study performed relatively well in clearing simulated sputum, suction will also reduce the moisture in the mouth. Thus, the actual effectiveness of EPSS in improving oral hygiene is uncertain. So the future design of the EPSS instruction should consider the solution of maintaining oral humidity by using moisturizing agents from time to time.

Weakness of the Automation

The EPSS can be switched on or off with a specific time set through the relay. However, the relay has to be connected to the computer to work so it means that the establishment of automation of EPSS requires hard-to-use, inaccessible hardware for patients to have. Moreover, the relay is not adaptable on both windows and mac systems thus the automation greatly restricts the accessibility of EPSS for patients. Such arrangement is also against the original initiation of the product as it seems to be inconvenient and difficult to use. So exertion should be paid on the amendment of EPSS in the future study. Putting the wireless switch on the relay to avoid the longtime use of a computer sounds feasible.

Inaccurate Results

Despite the experiment controlling the variables, most of the experiments did not repeat three times or more to reach statistical significance. Random and systematic errors may both exist and experiment results may be inaccurate. Thus, further experiments should be performed to get more consistent and precise results.

Completing future studies of the EPSS will obtain more detailed information about the safety concern of the procedure, the acceptance of the system among medical staff and the financial benefits of the EPSS and hardware improvement.

Conclusion

The EPSS works effectively for sputum suctioning in the laboratory setting. An investigation of the suction efficiency of three catheters (2mm, 4mm, 5.33mm) was carried out. The 4mm catheter is the most suitable to use in actual physiological conditions supported by the data. The automation of the system achieved by using the relay brings convenience for patients and their families. Oral care done by adequate clearance of oral secretion through EPSS is suggested to be valid in reducing the chance of aspiration pneumonia. All in all, EPSS may provide a new measurement for stroke patients to prevent the ASAP and improve their QOL after getting a stroke.

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