Bulbar dysfunction in normal pressure hydrocephalus: a prospective study

Ekawut Chankaew, MD,1 Prajak Srirabheebhat, MD,1 Sriwimon Manochiopinig, PhD,2 Theerapol Witthiwej, MD,1 and Itsara Benjamin, MD1

1Division of Neurosurgery, Department of Surgery, and 2Division of Speech-Language Therapy, Department of Rehabilitation Medicine, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand

OBJECTIVE Normal pressure hydrocephalus (NPH) is clinically characterized by gait disturbance, cognitive impairment, and urinary incontinence, as well as enlargement of the ventricles. To the best of the authors’ knowledge, there have been no previous publications regarding the correlation between bulbar dysfunction and NPH. The primary objective of this study was to compare preoperative and postoperative prevalence of bulbar dysfunction in patients with NPH. Secondary objectives included assessing the results of surgery for swallowing, speech, gait, cognition, and urination, and evaluating the correlation between bulbar dysfunction and triad symptoms.

METHODS Fifty-three patients with NPH who underwent shunt placement surgery at Siriraj Hospital were included in the study. Patients were evaluated for gait, cognition, urination, swallowing, and speech before and 6 months after shunt placement. Triad symptoms were assessed using standard methods. Bulbar dysfunctions were assessed using the Swallowing Problem Questionnaire, Thai Articulation Test, Resonation Screening Test (RST), and Thai Nasality Test. The Thai Speech Assessment Program and nasometer were used for objective speech measurement.

RESULTS Preoperatively, 86% (43/50) of patients had swallowing problems and 75% (37/49) had speech problems, as measured by the RST. Postoperatively, there was significant improvement in swallowing (p < 0.001), speech problems by RST (p = 0.008), and voice volume (p = 0.009), but no significant change in the nasometer test. All triad symptoms were improved. There were significant correlations between swallowing impairment and gait disturbance (r = 0.358, p = 0.009), and RST and cognitive impairment (r = −0.502, p < 0.001).

CONCLUSIONS This is the first study of bulbar dysfunction in patients with NPH. The results showed that the prevalence of bulbar dysfunction is very high. The correlation between bulbar dysfunction and the classic NPH triad has been documented and published. These bulbar symptoms also significantly improved after surgery. As such, bulbar dysfunction should be regarded as a core symptom that should be considered along with the classic triad in the clinical diagnosis and management of NPH.

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KEY WORDS normal pressure hydrocephalus; bulbar dysfunction; speech; swallowing; voice; resonance
nisms responsible for the associated clinical symptoms include reduction in blood flow and metabolism, and altered neuronal conduction due to stretching of periventricular white matter (PVWM). In 1965, Adams et al. proposed a triad of symptoms for NPH, consisting of gait disturbance, cognitive impairment, and urinary incontinence. Many other symptoms have been reported, including subsequent apathy, anxiety, depression, impaired wakefulness, and sexual dysfunction, but on our review of the literature, no previous studies have investigated and reported on bulbar dysfunction in NPH.

We observed that several patients with a history of frequent choking had been admitted to the intensive care unit because of aspiration pneumonia before a diagnosis of NPH was made. Soon after shunt placement surgery, these patients had no further episodes of aspiration or choking. Moreover, these patients experienced hoarseness or hypophonia, which is usually concomitant with some degree of aspiration. The cessation or reduction in severity of aspiration also occurs after the CSF tap test. These symptoms may be explained by a stretching of PVWM. An enlarged ventricle can affect corticospinal integrity, thereby causing gait disturbance in a patient with NPH. The corticobulbar tract may also be distorted or otherwise affected by the enlarged ventricle, resulting in bulbar dysfunction.

The primary objective of this study was to compare preoperative and postoperative prevalence of bulbar dysfunction in patients with NPH. Secondary objectives included assessing the results of surgery for swallowing, speech, gait, cognition, and urination, and evaluating the correlation between bulbar dysfunction and triad symptoms.

Methods
Study Design
This prospective study was conducted at the Division of Neurosurgery, Department of Surgery, Faculty of Medicine Siriraj Hospital, Mahidol University, during the study period from March 2013 to March 2015. The study protocol was approved by the Siriraj Institutional Review Board and written informed consent was obtained from all patients or their guardian/representative, when applicable.

Study Population
Candidates for our study were patients with probable NPH. The following inclusion and exclusion criteria were adopted. The inclusion criteria (all required) were as follows: 1) patients with more than 1 of the following symptoms: gait disturbance, cognitive impairment, and urinary incontinence; 2) patients with clinical symptoms that could not be completely explained by other diseases; 3) patients with ventricular dilation documented by CT or MRI; and 4) patients with CSF pressure lower than 20 cm H2O with normal CSF cell count. The exclusion criteria (at least 1 required) were: 1) patients with diseases or medical conditions of the head and neck region that could cause swallowing and speech problems (e.g., tumor, achalasia, esophageal spasm, reflux laryngitis, tracheostomy); 2) patients with neurological lesions that caused bulbar palsy; or 3) patients who were unable to speak.

Shunt Placement Procedures
Patients who met all of the above inclusion criteria were enrolled. Enrolled participants then underwent shunt placement surgery with a ventriculoperitoneal shunt (VPS) or lumbo-peritoneal shunt (LPS), depending upon surgeon and patient preference. Enrolled participants were evaluated before shunting and at 1, 3, and 6 months after surgery.

VPS placement was performed under general anesthesia using a programmable Codman Hakim Programmable Valve (Codman & Shurtleff, Inc.), Medtronic Strata II valve (Medtronic), or medium-pressure Medtronic valve (Medtronic), according to surgeon and patient preference. LPS placement was performed under general anesthesia using the programmable Medtronic Strata NSC valve (Medtronic). The initial pressure for the shunt system was set after surgery. Valve pressure was readjusted at postoperative intervals, as required. Shunt function was assessed regularly, especially when there was no improvement in clinical symptoms.

Outcome Measurements
The outcome measurements included: the number of steps and time (seconds) needed to walk 10 m at free speed; the Thai Mental State Examination (TMSE); and an ordinal urinary incontinence scale, in which the level of incontinence ranged from 1 to 6, with a higher score indicating a more incontinent condition.

Swallowing dysfunction was categorized into swallowing problems and speech problems. A swallowing problem was evaluated using the Swallowing Problem Questionnaire (SPQ) and a speech problem was evaluated using an articulation test, the volume and frequency of the voice, and resonance.

Swallowing Problem Questionnaire
Designed by Mano-chiopinig et al., the SPQ consists of 16 swallowing-related questions that relate to swallowing disorders, such as choking, hoarseness, wet/gurgly voice, dysphagia, spilling of food from the mouth, extra time needed to chew, and reduced eating. Each question represents 1 swallowing problem. All questions have 2 possible answers: the presence or absence of that swallowing-related symptom (symptom presence = 1, symptom absence = 0 points). The maximum score is 16, with a score of 0 indicating normal swallowing function. The patient or a relative was interviewed by a physician to facilitate the completion of the SPQ.

Speech Assessment
All patients were evaluated by a professional speech-language pathologist. The assessment consisted of 3 component parts.

Articulation Test. Patients were tested using the Thai Articulation Test (TAT), which consists of all Thai phonemes, including 21 initial consonants, 8 final consonants, 12 clusters, 24 vowels, and 5 tones in the Thai
language. Patients pronounce a list of words aloud until the test is completed and articulation is determined to be normal or abnormal.

**Volume and Frequency of Voice.** This component was assessed using the Thai Speech Assessment Program, a program developed by the National Electronics and Computer Technology Center, in Bangkok, Thailand. Using normal-conversation voice volume, patients count from 1 to 10 into a microphone that is connected to a computer. The software then computes and analyzes voice volume (dB) and voice frequency (Hz). The distance between the patient’s mouth and the microphone was 6 inches. Patients performed this exercise 2 times, with the average of the 2 times recorded as the test result.

**Resonation Testing**

Resonation is the speech quality that results from sound vibrations in the pharynx, oral cavity, and nasal cavity. Normal resonation is highly dependent on normal velopharyngeal structures and function. Velopharyngeal structures include the velum, lateral pharyngeal walls, and posterior pharyngeal wall. For normal speech resonation, the velopharyngeal port should be completely closed during the production of oral sounds (all Thai consonants, except /m, n, ng/ phonemes), sound energy should be blocked, and speech sound should be projected out through the oral cavity. When the velopharyngeal port is open during the production of nasal sounds (/m, n, and ng/ phonemes), sound energy is relatively unimpeded through the pharynx and nasal cavity.

Hypernasality is a resonance disorder that results from velopharyngeal inadequacy (VPI). Specifically, in patients with hypernasality, oral sounds inappropriately resonate into the nasal cavity due to inadequate closure of the velopharyngeal valve.

**TABLE 1. Swallowing Problem Questionnaire**

| Question                                      | Yes | No |
|----------------------------------------------|-----|----|
| 1. Difficulty swallowing                     | ☐   | ☐  |
| 2. Food struck in the throat                  | ☐   | ☐  |
| 3. Spill food from the mouth                  | ☐   | ☐  |
| 4. Getting food stuck in cheek                | ☐   | ☐  |
| 5. Refuse to eat                              | ☐   | ☐  |
| 6. Extra time needed to chew                  | ☐   | ☐  |
| 7. Smaller mouthful                           | ☐   | ☐  |
| 8. Eat less                                   | ☐   | ☐  |
| 9. Choking                                    | ☐   | ☐  |
| 10. Chronic cough                             | ☐   | ☐  |
| 11. Aspiration pneumonia                      | ☐   | ☐  |
| 12. Admission due to swallowing disorders     | ☐   | ☐  |
| 13. Wet or gurgly voice                       | ☐   | ☐  |
| 14. Hoarseness                                | ☐   | ☐  |
| 15. Weight loss                               | ☐   | ☐  |
| 16. Food textures require change (liquefying, chopping, pureeing, or nasogastric tube) | ☐ | ☐ |

**Total score**

**TABLE 2. Resonation Screening Test (RST)**

| Test                                                                 | Result |
|----------------------------------------------------------------------|--------|
| 1. Piti kub rod tuktuk pai ta lad pak kret seu pla kra bok pad ki lo  | Patient repeats the utterance 2 times, with and without the nostrils occluded. The examiner listens for differences in the quality of speech production. If speech quality does not change, this indicates that the patient has normal speech. |
| 2. Manee nung deum num ma now / Mhor young mai nud wan nae non / Nang ngam reum tum ngan | Patient repeats the utterance 2 times, with and without the nostrils occluded. The examiner listens for differences in the quality of speech production. If speech quality changes, this indicates that the patient has normal speech. |
| 3. Baimai baemeu bubee                                              | Patient produces the phonemes in a repetitive manner for three cycles. The examiner listens for differences in the quality of speech production. If speech quality does not change, this indicates that the patient has normal speech. |
| 4. Patient closes his/her mouth and builds up intra-oral air until cheeks are puffy and oral cavity is completely full of air | | |
| 5. Patient makes puffy cheeks similar to the preceding test (test 4), then protrudes his/her tongue | For tests 4 and 5 above, the examiner should note whether the patient was able to hold air in his/her mouth with or without (audible) nasal air emission | | |

**Total score**

**Subjective/perceptual assessment: Resonation Screening Test (RST).** The Resonation Screening Test (Iamharit P, Chuangsawanich A, Manochioponig S: Can the surgeon diagnose speech resonation problem by the speech resonation screening test. Paper presented at the 29th scientific conference, Royal College of Surgeons of Thailand, Pattaya, Chonburi, Thailand, July 31, 2004; Table 2), consists of a 5-item assessment for determination of VPI (hypernasality). The RST is composed of 3 short speech sentences and 2 examinations of velopharyngeal function. Each of the 5 items is rated as being either normal (successful) or abnormal (unsuccessful). Normal/successful outcome is given a zero score and abnormal/unsuccessful outcomes are given a score of 1. The maximum score is 5, with a score of 0 score indicating normal velopharyngeal function.

**Objective/instrument-based assessment: nasometer.** A nasometer (6200–3, Kay Elemetrics Corp.) is a computer-based instrument. This device consists of a headset that has directional microphones for the nose and mouth. These microphones are separated by a baffle that rests against the upper lip (Fig. 1). The microphones pick up acoustic energy from the nasal and oral cavities. The ratio of nasal to total (nasal plus oral) acoustic energy is then calculated. The calculated ratio is then multiplied by 100.
and expressed as a “nasalance” score. Individuals with VPI were assumed as having hypernasality, which manifested as high nasalance scores.\(^5,^{10,18,22,37}\)

Patients were asked to read 3 standard passages from the Thai Nasality Test.\(^25\) The first passage is a nasal passage that is rich in nasal consonants (m, n, ng), for which the velopharyngeal valve remains open to allow sound transmission into the nasal cavity. The second passage is an oral passage that is devoid of nasal consonants. The third passage is an oronasal passage that comprises a mix of oral and nasal consonants used in everyday conversation. Nasalance scores were compared with normative data of Thai subjects.\(^25\) This instrument provides objective information regarding resonance and nasality. In the present study, only the oronasal passage was used to determine whether resonance was hypernasality or not.

**Statistical Analysis**

Statistical analyses were performed using PASW Statistics (version 18.0, SPSS, Inc.). Data are presented as number (%), mean ± standard deviation (SD), or median and interquartile range (IQR). Comparisons between before and after shunt placement were performed using the Wilcoxon signed ranks test or McNemar’s test. Correlations were analyzed using Spearman’s rank correlation coefficient (\(r_s\)), Pearson’s correlation coefficient (\(r\)), or point-biserial correlation coefficient (\(r_p\)). A p value < 0.05 was considered statistically significant.

**Results**

**Characteristics of Patients**

There were 35 males and 18 females, with a mean age of 71.89 years. Of 53 patients who underwent shunt surgery, 3 patients were lost to follow-up at the 6-month time point for the following reasons: 1 patient died due to upper airway obstruction, 1 patient developed pneumonia with sepsis, and 1 patient suffered a traumatic intracranial hematoma (ICH; Fig. 2). Patient demographic data are shown in Table 3.

**Clinical Outcomes**

Patient clinical data are given in Table 4. Significant improvement was observed in all triad symptoms (gait, cognition, and urination) after shunt surgery (\(p < 0.05\); Table 4). Fifty-two patients improved in at least 1 of 3 triad symptoms. One patient was a nonresponder, having failed to improve in any of the 3 triad symptoms. The nonresponding patient also developed acute kidney injury at 1 month after shunt placement.

**Swallowing Assessment**

Fifty patients received swallowing assessment at 6 months postoperatively. Three patients were lost to follow-up for the reasons described immediately above. Preoperatively, 43/50 patients (86%) had swallowing problems. The maximum SPQ score in our study population was 10 points out of a possible maximum of 16 points (Fig. 3). The 5 most frequent symptoms were choking, chronic cough, hoarseness, wet/gurgly voice, and difficulty swallowing, respectively.

Six months postoperatively, 37/43 patients (86%) experienced improvement in swallowing. Of the 43 patients with preoperative swallowing deficits, 19 became symptom-free, 18 had decreasing symptoms, 5 had no change, and 1 patient’s symptoms worsened (\(p < 0.001\); Fig. 3). A statistically significant correlation was identified between a swallowing problem and gait performance before shunt placement (\(r = 0.358, p = 0.009\)). In addition, a swallowing problem was negatively correlated with TMSE (\(r = -0.394, p = 0.005\)) at 6 months after shunting.

**Speech Assessment**

Forty-nine patients were given a speech assessment at 6 months after shunt placement. Three patients were lost.
to follow-up for the reasons mentioned above, 1 of whom developed an ICH due to coagulopathy.

**Articulation Test**

Preoperatively, 33/49 patients (67%) had articulation disorders. The articulation of 28 patients remained abnormal postoperatively (Table 3). The main articulation problem was reduction or omission of /r/ and /l/ of the cluster sounds. There was no significant difference in articulation between before and after surgery (p = 0.18), but articulation correlated with gait performance prior to shunting ($r_p = 0.362$, $p = 0.008$).

**Volume and Frequency**

There was significant improvement in voice loudness ($p = 0.009$), but no significant change in voice frequency (Table 4). No correlation was identified between loudness and triad symptoms.

**Resonance**

Resonance Screening Test

Preoperatively, 37/49 patients (75.51%) had abnormal RST scores (Fig. 4). Postoperatively, 21/37 patients (56.75%) had an improved RST score. Of the 37 patients with preoperatively abnormal RST scores, 11 became zero RST scores, 10 had a decreased RST score, 13 had no change, and 3 experienced deterioration in their condition at 6 months after shunt placement. Of the 12 patients with preoperatively normal RST scores, 2 had increased RST scores and 10 remained at a normal RST score at 6 months after shunt placement. There was significant improvement in VPI when comparing preoperative and postoperative RST scores ($p = 0.008$). The RST was found to be negatively correlated with TMSE ($r = -0.502$, $p < 0.001$) before shunting.

**Nasometer**

Mean nasalance scores are shown in Table 4. Preoperatively, 11/49 patients (22.44%) had hypernasality. After shunt placement, only 8 patients still had hypernasality ($p = 0.54$). No significant difference was observed between preoperative and postoperative mean nasalance scores.

RST score was significantly correlated with both nasalance score ($r = 0.302$, $p = 0.028$) and hypernasality status ($r_p = 0.360$, $p = 0.008$) before shunt placement. In addition, normal resonance was statistically significantly correlated with better cognition (TMSE) before shunt placement ($r_p = 2.240$, $p = 0.025$).
Developed into whispering or no ability to speak at all. To became quiet and had slow speech that progressively de-

**Discussion**

In 1975, Adams remarked that his patients with NPH became quiet and had slow speech that progressively de-
veloped into whispering or no ability to speak at all. To the best of our knowledge, this is the first study to address bulbar dysfunction in NPH. Of 53 probable patients with NPH, only 1 was identified as a nonresponder after shunt placement surgery. Preoperatively, 86% of patients with NPH had swallowing problems and 75% had speech deficits due to velopharyngeal inadequacy. After shunt placement, significant improvement was observed in swallowing function, speech characteristic (resonation), and speech quality (increasing volume). Statistically significant correlations were found between swallowing problem and gait disturbance, articulation disorder and gait disturbance, and speech problem and cognitive impairment. Interestingly, no previous investigation has reported on bulbar dysfunction in NPH, even though dysphagia is a very common feature in neurological disorders. Dysphagia has been reported to affect 22%–65% of patients with acute stroke, 36% of symptomatic patients with Parkinson’s disease, and more than 30% of patients with multiple sclerosis. Rosler et al. reported an inverse relationship between Mini-Mental State Examination score and severity of swallowing impairment. The present study found bulbar dysfunction in NPH to be as high as 86%. We also found bulbar dysfunction to be significantly correlated with TMSE score.

This study had 15 patients with secondary NPH (28%). One patient was lost to follow-up due to pneumonia with sepsis. The diseases of the patients before NPH consisted of 7 with supratentorial tumor, 3 with supratentorial ICH, 2 with subarachnoid hemorrhage, 1 with traumatic epidural hematoma, and 1 with previous craniectomy. None of the patients had bulbar symptoms when they had these diseases before NPH and they experienced a good recovery after treatment. As such, the comorbid disease of second-
ary NPH in the present study should not have caused the bulbar palsy. The patients with neurological lesions that cause bulbar palsy were not enrolled because of the exclusion criteria.

Based on our clinical experience, we observed that severity of bulbar symptoms correlated well with late or worsening NPH triad symptoms, which were usually found in cases with severe apathy or sleepiness. Inadequate drainage after CSF shunting also correlated with worsening of bulbar symptoms. In most cases, bulbar symptoms respond dramatically to both CSF shunting and the CSF tap test. As such, they can be used as landmark symptoms for diagnosis and treatment monitoring.

There are 2 possible pathoanatomical causes of bulbar dysfunction in NPH. The first cause involves PVWM damage. Levine et al. demonstrated that increasing PVWM density is correlated with worsening NPH triad symptoms. Based on our clinical experience, we observed that severity of bulbar symptoms correlated well with late or worsening NPH triad symptoms, which were usually found in cases with severe apathy or sleepiness. Inadequate drainage after CSF shunting also correlated with worsening of bulbar symptoms. In most cases, bulbar symptoms respond dramatically to both CSF shunting and the CSF tap test. As such, they can be used as landmark symptoms for diagnosis and treatment monitoring.

The location of the CBT is close to the CST at the lateral ventricle level. The corticobulbar tract (CBT) to be anteromedial to the CST at the lateral ventricle level. The

### TABLE 3. Demographic data, clinical characteristics, and duration of symptoms in 53 patients with NPH

| Variable                        | Value |
|---------------------------------|-------|
| Mean age in yrs (range)         | 71.89 (49–87) |
| Sex (M/F)                       | (35/18) |
| Disease (%)                     |       |
| Idiopathic NPH                  | 38 (71.7) |
| Secondary NPH                   | 15 (28.3) |
| Median duration of symptoms in mos (IQR) | |
| Gait                            | 12 (6–24) |
| Cognitive                       | 12 (6–42) |
| Incontinence                    | 12 (4–24) |
| Mean Evan ratio ± SD            | 0.334 ± 0.03 |
| Mean CSF pressure ± SD (cm H₂O) | 14.22 ± 4.38 |
| Shunt type (%)                  |       |
| Programmable VPS                | 30 (56.6) |
| Conventional VPS                | 3 (5.7) |
| Programmable LPS                | 20 (37.7) |

### TABLE 4. Clinical parameters and voice assessments before surgery and at 6 months after shunt placement surgery*

| Variable                        | Preop | Postop | p Value |
|---------------------------------|-------|--------|---------|
| Median gait (IQR)†              |       |        |         |
| No. of steps in 10 m            | 33.5 (22–56) | 29.5 (19–47) | 0.025 |
| Seconds in 10 m                 | 26.5 (13–53) | 17.6 (12–35) | 0.035 |
| Cognitive‡                      |       |        |         |
| Mean TMSE ± SD                  | 18 ± 7 | 23 ± 7 | <0.001 |
| Incontinence (%)                | 46 (92) | 33 (66) | <0.001 |
| Abnormal articulation (%)       | 33 (67) | 28 (57) | 0.18   |
| Mean volume ± SD (dB)           | 69.38 ± 4.91 | 71.78 ± 5.08 | 0.009 |
| Mean frequency ± SD (Hz)        | 169.32 ± 37.46 | 168.50 ± 34.00 | 0.833 |
| Mean % nasalance score ± SD     |       |        |         |
| Oral sound                      | 24 ± 14 | 21 ± 9 | 0.146  |
| Oronasal sound                  | 40 ± 9  | 38 ± 9 | 0.242  |
| Nasal sound                     | 54 ± 12 | 53 ± 10 | 0.379  |
| Hypernasality (%)‡              | 11 (22.44) | 8 (16.32) | 0.54   |

* Boldface type indicates statistical significance.
† In 50 patients.
‡ In 49 patients.
CBT can be distorted by either or both enlarged ventricles and/or reduced CBF. Moreover, Rogers et al. reported that ventricular dilation causes heterogeneous displacement and deformation on the periventricular fiber tracts.40

The second cause is hypoperfusion around the Sylvian fissure region42 in NPH, which is the location of the swallowing and laryngeal motor cortex.38,44 Hypoperfusion at the perisylvian cortex can be explained by dilation of the Sylvian cistern, which is a common finding in idiopathic NPH.33,50

Both impaired CBT and cortical control of bulbar functions may have resulted in swallowing and speech problems in this study. Therefore, increased perfusion in these areas after shunt placement may have resulted in improvement in bulbar dysfunction.

We found significant improvement in VPI after shunt placement according to the RST, but changes in nasometer results did not reach statistical significance. As expected, we found the RST score to be significantly correlated with both nasalance score (r = 0.302, p = 0.028) and hyperna-
salinity status ($r_p = 0.360, p = 0.008$) before shunt placement. This finding was not surprising, because these two assessment techniques measure the same phenomena and do so in the same way. High nasalance scores were expected among individuals who were judged as having hypernasality, because both the nasometer and the human ear are sensitive to speech in which nonnasal consonants are predicted with increased nasal resonance. Thus, the RST can be used as effectively as auditory perceptual assessment.

Regarding the oronasal nasalance score, which reflects nasality in normal conversation, we found a mean oronasal nasalance score in our patients with NPH of about 40%. This is in agreement with the previous study by Manonasalance score in our patients with NPH of about 40%. This is in agreement with the previous study by Mano- 

Sensitivity to speech in which nonnasal consonants are pre- 

tected with increased nasal resonance. Thus, the RST can 

be used as effectively as auditory perceptual assessment. 

This finding was not surprising, because these two assess 
ments observed in gait disturbance. As such, these symp- 
toms improve both diagnosis and treatment monitoring in 
nonambulatory patients with NPH.

This study has some notable limitations. There are 
several potential reasons for the finding of no significant 
change in postoperative nasalance score, the first of which is 
speaking behavior. Some patients in our study had hy- 
ponasality speech for nasal consonants (/m, n, ng/) or 
hypernasality speech for oral consonants used in normal 
conservation. For example, speakers who habitually fail to 
open their mouths properly/widely may produce hyper- 
nasal speech. In another setting, speakers with allergies 
who have recurrent nasal congestion tend to have denasal/ 
hyponasal speech. This may cause a false-positive result. 
Secondly, the nasometer test requires long spoken pas- 
sages and is time-consuming. Accordingly, patients with 
poor cognition may lose attention and become uncoopera- 
tive. Consistent with that assumption, our results showed 
normal resonance to be significantly correlated with bet- 
ter cognitive scores (TMSE) before shunt placement ($r_p = 
2.240, p = 0.025$), whereas RST score was negatively cor- 
related with TMSE ($r = -0.502, p < 0.001$) before shunt 
placement. This implies that only patients who had good 
cognition would respond to the nasometer test. It can also 
be argued that the RST score may be more appropriate than 
the nasometer in patients with NPH, because the RST 
takes less time and is easier to conduct/perform. Thirdly, 
there could also be a potential selection bias in the inclu- 
sion criteria in that patients with the worst speech may 
have been those who might have had the greatest speech 

improvement after shunt placement, but they were exclud- 
ed due to not being able to complete the nasometer test. 

Regarding the articulation test, we expected the results 

were not significantly different after shunt placement be- 
cause of the influence of dialects and speaking behavior.

Speech is a complex sensory-motor task. Speech is, there- 
fore, vulnerable to neurological damage, but the objective 
measurement of speech is difficult. Our results showed a 
decreased mean nasalance score after shunting, but the de-
crease was not statistically significant. Moreover, subject- 
tive symptoms and the RST score were also significantly 

improved, with a significant correlation observed between 
RST and nasalance score.

Another limitation of this study was the lack of a con- 

trol group (without NPH), against which we could have 
compared our findings. Moreover, bulbar dysfunction is 
commonly observed in the elderly and this must be ac-
nowledged as a potential bias. However, and while this 
may be a weakness, we do not believe that this factor in-
validates our results. These acknowledged weaknesses 
should be considered and factored into any future studies 
in bulbar dysfunction in NPH.

As described above, bulbar dysfunction is common in 
patients with NPH. Unusual presentation of NPH symp-
toms may hinder early diagnosis and prolong initiation of 
proper treatment. Bulbar symptoms may appear before 
triad symptoms, especially in atypical cases or in nonam-
bulatory patients. The present study showed that bulbar 
symptoms respond well to surgery, similar to the improve-
ments observed in gait disturbance. As such, these symp-
toms improve both diagnosis and treatment monitoring in 
nonambulatory patients with NPH.

Conclusions

This is the first study of bulbar dysfunction in patients 
with NPH. The results showed that the prevalence of bul-
bar dysfunction is very high. A correlation between bulbar 
dysfunction and the classic NPH triad has been document-
ed and published. Bulbar symptoms also significantly 
improved after surgery. As such, bulbar dysfunction should 
be regarded as a core symptom that should be considered 
along with the classic triad in the clinical diagnosis and 
management of NPH.

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Conception and design: all authors. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: Benjamin, Chankaew, Srirabheebhat, Manochiopinig. Reviewed submitted version of manuscript: Benjamin, Chankaew, Srirabheebhat, Manochiopinig. Reviewed submitted version of manuscript: Benjamin, Chankaew, Srirabheebhat, Manochiopinig. Reviewed submitted version of manuscript: Benjamin, Chankaew, Srirabheebhat, Manochiopinig. Administrative/technical/material support: Chankaew, Manochiopinig, Witthiwej. Study supervision: Chankaew, Srirabheebhat.

**Correspondence**
Itsara Benjamin, Division of Neurosurgery, Department of Surgery, Faculty of Medicine Siriraj Hospital, Mahidol University, 2 Prannok Rd., Bangkoknoi, Bangkok 10700, Thailand. email: oak_safehouse@hotmail.com.