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Original Article

Dysphagia Screening Using High-resolution Impedance Manometry in Acute Stroke

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SUMMARY

Background: Dysphagia is relatively common in patients with acute stroke and can lead to aspiration pneumonia and malnutrition. We evaluate the usefulness of dysphagia test using high-resolution impedance manometry during acute stroke.

Methods: Consecutive patients with acute stroke were enrolled, and all patients were stratified into three aspiration risk groups. High-resolution impedance-manometry (HRiM) was performed in patients with an intermediate aspiration risk. The diet plan was determined based on the results of evaluations and clinical outcome was determined by improved diet program and pulmonary complications.

Results: A total of 293 patients with acute stroke were enrolled. Among 91 patients with intermediate-risk, 36 revealed an impaired swallowing pattern in HRiM. Fifty-five patients with a preserved swallowing pattern and 169 with low-risk were started with a general diet and tolerated it well. Thirty-six patients with an impaired swallowing pattern were recommended for swallowing rehabilitation and a stepwise dysphagia diet of which 97.2% successfully adapted to the general diet. High-risk group patients received nasogastric tube feeding immediately. During admission, no patients with low- and intermediate-risk developed aspiration pneumonia. However, aspiration pneumonia frequently occurred in high-risk group patients.

Conclusions: Our assessment program was safe and effective for assessing swallowing function and for determining the appropriate diet plan.

1. Introduction

Stroke is a devastating event that carries a potential for long-term disability[1]. Malnutrition is frequently observed in patients with stroke, and dysphagia contributes to the malnutrition risk. Dysphagia is a common complication of the acute stroke stage[2]. The presence of dysphagia and associated aspiration increases the risks for pneumonia, mortality, and prolonged hospital stay[2–7].

Clinical bedside assessment is the simplest measure, which does not require much time or instruments. However, this assessment misses up to 40% of patients who aspirate (so-called silent aspirators)[7–9]. The modified barium swallow (MBS) is the alternative test for evaluating overall swallowing from a visual aspect. Although helpful clinically, the limitations of this technique are well known, as it does not always provide detailed diagnostic information about subtle abnormalities of the pharyngeal and esophageal musculature or transit. Furthermore, MBS carries a risk of aspirating contrast medium and chemical pneumonitis. Videofluoroscopy and videoendoscopy have also been used to identify the swallowing process and aspiration[10,11], but they require special techniques.

High-resolution manometry (HRM) has widened the pharyngeal domain and enables highly accurate spatiotemporal interpolation of dynamic pressure changes caused by luminal closure following contraction. HRM also allows for intuitive quantification of pharyngeal movements and of the opening of the upper

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esophageal sphincter (UES), as well as their timing[12]. Although some patients may feel uncomfortable during test, the procedure is generally safe and serious side effects are extremely rare[13]. Recent studies have revealed videofluoroscopic measurements of the swallowing function are significantly correlated with manometric analysis in patients with brainstem stroke[14].

In acute stroke patients, we investigated whether high-resolution impedance manometry (HRiM) is clinically useful to evaluate dysphagia in patients with acute stroke.

2. Methods

2.1. Patients

This study protocol (*D*ysphagia screening in *A*cute *S*troke using *H*igh-resolution impedance manometry (DASH)) was approved by the institution review board of Seoul St. Mary's Hospital, and informed consent was obtained from all participants or their relatives. Consecutive patients with acute stroke at the neurology department were enrolled. The clinical information obtained included age, gender, history of hypertension, diabetes mellitus, dyslipidemia, heart disease, and current cigarette smoking. All patients underwent a detailed clinical evaluation, including a neurological examination, laboratory tests, chest radiography, electrocardiography, 24-h Holter monitoring, brain magnetic resonance imaging (MRI), and contrast-enhanced MR angiography. Severity of stroke was assessed using the National Institute of Health Stroke Scale (NIHSS). Stroke was defined based on clinical history and the neurological examination with compatible new lesions on MRI. Patients were excluded if they had (1) hyperacute stroke and were receiving thrombolytic therapy; (2) symptom onset > 48 h; (3) history of stroke and dysphagia; (4) other neurological diseases causing oropharyngeal dysphagia, such as parkinsonism, dementia, and neuromuscular disorders; (5) history of cranial neurosurgery; (6) prior or current structural lesions causing oropharyngeal dysphagia; or (7) pulmonary diseases such as chronic obstructive pulmonary disease or pneumonia. In addition, patients who died in the incipient stage of acute stroke, and those with neurological deterioration (increase in NIHSS $\geq$ 4) and transient ischemic attack were also excluded in a retrospective manner.

2.2. Study protocol

The protocol consisted of two evaluation steps; the first step was to identify patients with risk of possible aspiration and the second step was for detecting silent aspirators. The first step was performed on hospital days 1 and 2 and the second step was done on hospital day 2.

2.3. Step 1: neurological evaluation and bedside water swallow test

Patients were interviewed regarding difficulties with food intake, chewing, and swallowing, and neurological signs were confirmed.

Patients with impaired consciousness (stupor or coma) and those were unable to sit upright or control their head, were categorized to be at high risk of aspiration pneumonia, and they received immediate nasogastric tube feeding without further testing. The remaining patients underwent a bedside indirect water swallow test. This swallowing screening consisted of an initial saliva swallow followed by escalated intake of up to 10 mL of water (saliva, 2, 5, and 10 mL water). Failure on the water swallow test was defined if one of the four aspiration signs (deglutition, cough, drooling, and voice change) was positive. Patients who did not pass this step were also categorized into the high-risk group, and nasogastric tube feeding was performed.

The remaining subjects were classified into low- and intermediate-risk groups according to oropharyngeal neurologic deficits (if any one of following was positive, the patient was categorized into the intermediate-risk group: (1) dysarthria, (2) motor or global aphasia, (3) inability to close and open lips, (4) facial weakness, (5) tongue deviation, (6) uvular deviation, (7) loss of gag reflex, or (8) inability to cough voluntarily). The low-risk group was permitted to start a general diet and the intermediate risk group underwent the step 2 test.

2.4. Step 2: HRiM testing

HRM was performed using a solid HRiM catheter with a 4.2 mm outside diameter, 36 circumferential sensors spaced at 1-cm intervals, and 14 impedance recording rings (12 impedance segments) spaced at 2-cm intervals (Sierra Scientific Instruments, Los Angeles, CA, USA). Patients fasted for at least 6 h before the examination, and the tests were conducted in a sitting or semi-Fowler position. The assembly was placed to record from the hypopharynx to the proximal stomach with approximately five intragastric pressure sensors, and the catheter was fixed in place by taping it at the nostril. The impedance sensors were thus positioned from the UES through the distal esophagus and into the proximal stomach.

Basal UES and lower esophageal sphincter (LES) pressures were measured during and at 30 s after dry swallowing. Pharyngoesophageal peristalsis was measured using 15 swallows of 5 mL of normal saline at 30-s intervals. The next step was the multiple rapid swallow (MRS) test with 200 mL of water within 10–20 s to evaluate activity of the deglutitive vagal inhibitory pathway. Finally, the HRiM catheter was pulled back by 15 cm, and the same sessions were repeated because of inability to assess all the pharyngeal manometric information and bolus transit of the pharyngoesophageal segment.

Pressure topography parameters were analyzed using the Chicago classification for the liquid swallows with a modification for pharyngeal function monitoring[15–18]. The proximal contractile integral quantifies contractile activity in a space-time box by multiplying the length from the velopharynx to the hypopharynx by the duration of contractile wave front propagation, and the mean pressure in the entire box excluding pressures <20 mmHg. The transition zone was defined as the distance between the proximal and distal esophageal contractile segments with an isobaric contour at 30 mmHg.

Impedance flow analysis for each water swallow was conducted for bolus clearance. Multichannel impedance sensors detected bolus entry and exit at four levels. Bolus transit was assessed by defining bolus entry and bolus exit at each level. Bolus entry was considered as a decline in impedance $\geq$50% from baseline, and bolus exit was determined as return to this 50% point on the impedance recovery curve. Complete bolus transit was confirmed by defining the bolus entry and sequential bolus clearance at all impedance-recording sites. This was measured by percentage of waves, which had complete bolus transit, and $\geq$80% of the measured value was regarded as normal[19].

All HRiM tracings were analyzed using ManoView analysis software 2.0. All data were corrected for thermal sensitivity of the pressure-sensing elements using the thermal compensation function in ManoView.

The impaired swallowing patterns were defined through the real-time assessments of the HRiM system and clinical presentation during the HRiM test. If the liquid was not cleared after one swallow, the pateint was considered to have an impaired swallowing pattern. In addition, patients with (1) continuous complaints of swallowing difficulties during the HRiM test, (2) defects in bolus

control during the lip and oral phase and/or clinical signs of water dribbling from the mouth, and (3) severe abnormal HRiM findings, such as incomplete UES opening and bolus retention on the UES/pharynx, were considered to have an impaired swallowing pattern.

2.5. Diet decision and rehabilitation plan

A diet plan was decided based on the result of step 2 for the remaining intermediate-risk group; patients with a preserved swallowing pattern were permitted to have a general diet, and those who had impaired pharyngoesophageal function underwent swallowing rehabilitation training and were guided as per the National Dysphagia Diet level[20]. The interventions included position education as well as individualized exercises designed to strengthen muscles involved in respiration, phonation, and articulation, which play key roles in remediation of swallowing disorders.

2.6. Outcome measures

The clinical outcome was determined by improvements in the diet program of each patient and pulmonary complications. The patients also answered visual analogue scales (0–10 numeric rating) that measured their level of overall satisfaction regarding improvement of their symptoms at 1 month after admission.

2.7. Statistical analysis

Statistical analyses were performed with SPSS ver. 24.0 (SPSS, Inc., Chicago, IL, USA). Independent sample *t*-tests or one-way analysis of variance with Bonferroni post hoc testing were used to compare the means. Pearson's chi-square test was used to compare categorical variables. A $p < 0.05$ was considered significant.

3. Results

3.1. General patient characteristics

Among the 293 patients enrolled, 152 (51.9%) were men. Mean (±standard deviation) age was 66.0 ± 14.1 years. One-hundred seventy patients (58.0%) had hypertension, 83 (28.3%) had diabetes, 111 (37.9%) had dyslipidemia, and 57 (19.4%) had heart disease. Eighty-four patients (28.7%) were current smokers, and 51 (17.4%) were ex-smokers. The mean times between onset and hospital visits were 18.6 ± 8.4 and 25.7 ± 7.4 h, respectively. The initial NIHSS averaged 5.3 ± 3.5, and the mean duration of admission was 6.4 ± 7.0 days.

A flowsheet and protocol results are summarized in Fig. 1. Dysphagia was assessed successfully in all patients. Twenty-nine patients with severe neurologic deficits and four patients who showed one or more aspiration signs on the indirect water swallow test were categorized as the high-risk group and they received immediate nasogastric tube insertion and adequate position/physical therapies with frequent oral suctioning to prevent aspiration. A total of 169 and 91 patients were classified into the low- and intermediate-risk groups in accordance with the presence of oropharyngeal neurologic signs, respectively. Mean age at onset was higher, and female-gender was predominant in the high-risk group. The proportions of dyslipidemia and heart disease differed among the groups. The NIHSS scores and mean admission duration were higher in the high-risk group (Table 1).

3.2. HRiM findings

Ninety-one patients in the intermediate-risk group underwent HRiM, and no adverse events were observed during the test. Thirty-six of the 91 patients had impaired swallowing patterns and had a tendency to be associated with a higher NIHSS score, longer

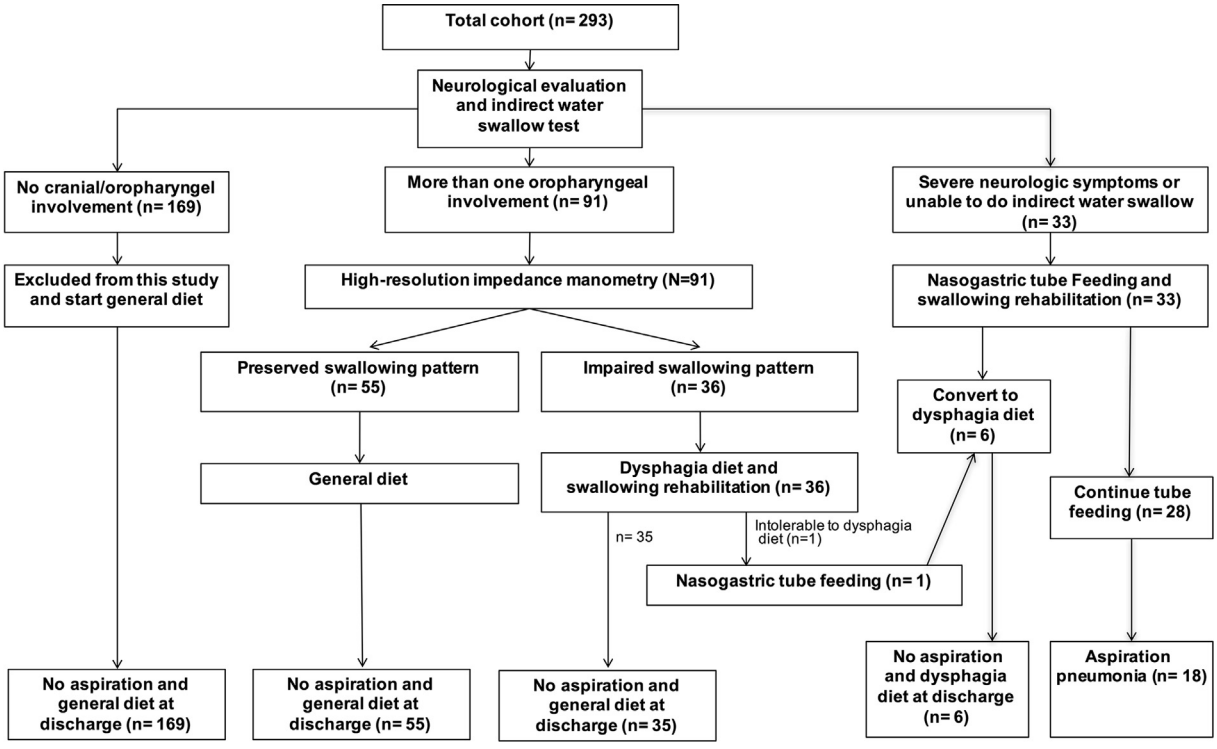

Fig. 1. Flow diagram for recruitment.

Table 1
General characteristics of total patients.

		Risk stratification			P	Post *hoc* analysis
		Low (n = 169)	Intermediate (n = 91)	High (n = 33)		
Age, y, mean ± SD		65.0 ± 14.4	65.2 ± 12.7	73.4 ± 14.3	0.006	low = intermediate < high
Gender, male (%)[a]		89 (52.7%)	54 (59.3%)	9 (27.3%)	0.006	
Hypertension (%)[a]		94 (55.6%)	58 (63.7%)	18 (54.5%)	0.410	
Diabetes mellitus (%)[a]		46 (27.2%)	27 (29.7%)	10 (30.3%)	0.884	
Dyslipidemia (%)[a]		50 (29.6%)	43 (47.3%)	18 (54.5%)	0.002	
Heart disease (%)[a]		28 (16.6%)	12 (13.2%)	17 (51.5%)	<0.001	
Smoking (%)[a]	Ex-smoker	31 (18.3%)	14 (15.4%)	6 (18.2%)	0.226	
	Current smoker	51 (30.2%)	29 (31.3%)	4 (12.1%)		
Initial NIHSS, mean ± SD		3.6 ± 1.2	5.2 ± 1.3	14.4 ± 1.6	<0.001	low < intermediate < high
Hospitalization day, mean ± SD		4.5 ± 2.4	5.8 ± 7.2	17.7 ± 11.1	<0.001	low = intermediate < high

Abbreviations: NIHSS; National Institute of Health Stroke Scale.
Analyses were performed by one-way analysis of variance (ANOVA) with Bonferroni post hoc testing, and by the χ^2 test[a].

hospital stay and more oropharyngeal neurologic signs (1.6 ± 0.6 vs. 2.4 ± 0.6, p < 0.001) (Table 2). Manometry in the impaired swallowing pattern group showed a significantly shorter UES opening time, longer transition zone, and lower pharyngeal contractile integral and basal UES pressure compared to those with a preserved swallowing pattern (Table 3). An abnormal response to the MRS test was observed in 56 (61.5%) patients; among the patients with preserved swallowing pattern, 26 (47.3%) showed abnormal deglutitive inhibition; 30 of 36 patients with impaired swallowing pattern showed disordered inhibition (χ^2 = 11.954, p = 0.001). Mean time (seconds) to drink 200 mL of water was also higher in the group with an impaired swallowing pattern (preserved swallowing pattern vs. impaired swallowing pattern = 33.2 ± 22.1 vs. 59.2 ± 33.1, p < 0.001 by independent sample *t*-test). In the impedance test, all patients with a preserved swallowing pattern showed complete clearance of water from the pharyngeal area after a single swallow (complete bolus transit on the UES area), and no remnant flow was observed on the pharyngeal area, whereas 29 of 36 patients with an impaired swallowing pattern showed frequent remnant flow on the pharyngeal area after a single swallow (incomplete bolus transit) (χ^2 = 65.029, p < 0.001).

3.3. Clinical outcomes

Aspiration pneumonia developed in 0, 0, and 18 (62.1%) patients in the low-, intermediate-, and high-risk groups. All patients with low-risk maintained their general diet during the hospital course. Fifty-five patients with a preserved swallowing pattern in the intermediate-risk group maintained their general diet without any complications. Five patients with high aspiration risk converted to the step 2 dysphagia diet and the remaining 28 patients retained a nasogastric tube at discharge. Among 36 patients with impaired swallowing patterns, 97.2% (35/36) successfully adapted to a general diet from the stepwise dysphagia diet at discharge. Only one patient who failed to adapt to the dysphagia diet received a feeding tube.

The overall satisfaction for this program was 8.2 ± 2.2, 9.5 ± 0.2 and 7.0 ± 3.2 in order of the low-, intermediate- and high-risk groups, respectively.

4. Discussion

Dysphagia is defined as difficulty swallowing food, liquid, or both. If it is not detected early, dysphagia can lead to serious complications, including aspiration pneumonia, malnutrition, and death. Additionally, dysphagia increases the need for hospitalization, length of hospital stay, and overall health care costs[21]. Accordingly, early screening of swallowing function and detection of dysphagia in acute stroke patients not only reduces these complications but also reduces length of hospital stay and overall healthcare expenditures[22–25].

Results of this clinical investigation suggest that early swallowing screening and dietary and multidisciplinary diagnostic and rehabilitation interventions can be successful and efficient for managing patients with acute stroke and dysphagia. Because the goal of early assessment for dysphagia is to formulate safe and adequate nutrition and to prevent aspiration pneumonia, we used stepwise assessments to identify aspiration risk severity. We easily stratified the patients into three groups after step 1; this simple evaluation process provided sufficient evidence for risk estimation in each group and suggested an immediate diet plan, at least in the low- and high-risk groups. However, predicting aspiration risk and determining diet in the intermediate-risk group was difficult. Use of the water swallow test can be effective for discriminating “overt

Table 2
Clinical characteristics of intermediate aspiration risk group.

		Preserved swallowing pattern (n = 55)	Impaired swallowing pattern (n = 36)	P
Age, y, mean ± SD		64.9 ± 11.8	65.6 ± 14.1	0.785
Gender, male (%)[a]		31 (56.4%)	23 (63.9%)	0.475
Hypertension (%)[a]		34 (61.8%)	24 (66.7%)	0.638
Diabetes mellitus (%)[a]		18 (32.7%)	9 (25.0%)	0.430
Dyslipidemia (%)[a]		24 (43.6%)	19 (52.8%)	0.393
Heart disease (%)[a]		3 (5.5%)	9 (25.0%)	0.007
Smoking (%)[a]	Ex-smoker	7 (12.7%)	7 (19.4%)	0.600
	Current smoker	17 (30.9%)	12 (33.3%)	
Initial NIHSS, mean ± SD		4.3 ± 0.8	6.6 ± 0.7	<0.001
Hospitalization day, mean ± SD		4.0 ± 1.4	8.6 ± 10.9	0.003

Abbreviations: NIHSS; National Institute of Health Stroke Scale.
Analyses were performed by independent sample *t*-test and by the χ^2 test[a].

Table 3
High-resolution manometry findings of intermediate aspiration risk group.

	Preserved swallowing pattern (n = 55)	Impaired swallowing pattern (n = 36)	P
Pharyngeal functions			
Basal UES pressure (mmHg)	36.7 ± 20.8	26.7 ± 14.0	0.007
Residual UES pressure (mmHg)	2.9 ± 5.2	3.4 ± 11.2	0.797
UES opening duration (msec)	570.8 ± 195.2	442.1 ± 180.3	0.002
UES opening within 440 msec, n (%)[a]	14 (25.5%)	24 (66.7%)	<0.001
Transition zone (cm)	2.9 ± 3.7	5.7 ± 4.3	0.002
PCI(mmHg-s-cm)	347.8 ± 159.7	230.6 ± 123.1	<0.001
dP/dT (mmHg/msec)	18.1 ± 22.8	18.5 ± 22.7	0.937
Pharyngeal peak pressure at 4 cm above mid UES(mmHg)	173.9 ± 109.3	139.5 ± 62.1	0.059
Pharyngeal peak pressure at 2 cm above mid UES(mmHg)	159.4 ± 72.6	133.0 ± 46.0	0.036
Esophageal functions			
Basal LES pressure (mmHg)	19.4 ± 12.3	18.8 ± 12.7	0.818
Residual LES pressure (mmHg)	6.6 ± 6.6	6.7 ± 6.0	0.907
Wave amplitude at 11 cm above LES (mmHg)	76.9 ± 42.3	56.8 ± 33.3	0.014
Wave amplitude at 7 cm above LES (mmHg)	88.0 ± 43.2	74.8 ± 48.3	0.190
Wave amplitude at 3 cm above LES (mmHg)	88.9 ± 50.1	75.1 ± 6.7	0.174
DCI(mmHg-s-cm)	1705.8 ± 1368.7	1322.0 ± 1399.0	0.201
Intrabolus pressure	14.9 ± 7.1	17.7 ± 15.8	0.325

Abbreviations: UES = upper esophageal sphincter, PCI = pharyngeal contractile integral, dP/dT = velocity on 2 cm−4 cm above mid UES, LES = lower esophageal sphincter, DCI = distal contractile integral.
Analyses were performed by independent sample *t*-test.
[a] Analysis was performed by the χ^2 test.

aspirators". However as previous studies have indicated[7–9], this test misses up to 40% of patients who have one or more oropharyngeal neurologic signs. Among the intermediate-risk group patients, 36 (39.6%) with impaired swallowing patterns showed frequently bolus retention on UES, abnormality on UES opening, lower pharyngeal contractile integral, a reduction in hypopharyngeal swallowing pressures, longer transition zone length, and a double swallow pattern. The majority of these patients revealed remnant flow on the pharyngeal area after a single swallow (incomplete bolus transit) on the impedance test, and many showed vagal inhibitory dysfunction on UES and the esophageal body. UES opening is incomplete if vagal inhibitory output is inappropriate. Accordingly, flow transition may be inhibited in this condition. Our results suggest that this misprogrammed excitatory output from the central pattern generators of the brainstem caused an abnormal pressure-traveling pattern during pharyngeal swallowing. Through this program, the intermediate-risk group with an impaired swallowing pattern was defined as "possible aspirators" and they underwent swallowing rehabilitation. After this rehabilitation program, the occurrence of aspiration pneumonia decreased to zero in the intermediate-risk group, and nearly all patients with intermediate-risk had switched to a general diet at discharge. More importantly, this program can alert patients with acute stoke to the danger of aspiration and dysphagia.

The limitations of the present study include the following. We did not compare this method with other commonly used techniques. Comparison with a gold standard or a usual care group would be necessary to validate or prove superiority of DASH in this setting. This assumption is supported by the established assessment that the HRM finding is associated with videofluoroscopic finding for measurements of swallowing function in patients with brainstem stroke[14]. Second, the topography of the stroke lesions was not analyzed. In addition, the investigators were not blinded to the dysphagia test results; however, we do not believe that this significantly influenced the results, as our study design was well suited for a clinical situation. Finally, there were confounding effects that developed by treating all oropharyngeal signs as equivalent factors.

In summary, we showed that an assessment program for dysphagia could be used as a screening tool for detecting aspiration risk in patients with acute stroke. This protocol was useful for determining the diet mode. Early assessment and diagnosis is helpful when formulating an intervention plan that provides for safe and adequate nutrition. The HRiM test provided useful information from both visual and functional aspects.

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