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Original article

Development and effectiveness of exercise rehabilitation system for dysphagia using information and communication technology systems

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Abstract

Objective: In older patients, dysphagia is a major risk factor for aspiration pneumonia and choking as it progresses slowly and recurs repeatedly without awareness. Information and communication technology (ICT) is used in various medical fields. However, no feeding or swallowing disorder prevention program has been developed to date and no reports have verified its effectiveness and safety. This study aimed to develop a dysphagia rehabilitation system using ICT and verify its effectiveness.
Methods: Changes in swallowing function and functional prognosis were examined in 120 patients with aspiration pneumonia: 60 in the control and 60 in the ICT group. Physical therapists performed pulmonary rehabilitation in the control group. There were additional activities within the ICT rehabilitation system, such as motor and swallowing function evaluations, training sessions, and provision of dietary instructions, in addition to the rehabilitation content of the control group.
Results: The Functional Oral Intake Scale (FOIS) score, a measure of swallowing function, significantly improved in the ICT group (P<0.001). ICT use was considered an influencing factor of FOIS change (β=0.49, 95% confidence interval, 1.47 to 2.97 P<0.001). ICT use positively affected the Barthel index gain (β=0.49, 95% confidence interval, 14.73 to 32.72 P<0.001).
Conclusion: A rehabilitation program using ICT improved swallowing function and the Barthel index. The system can also be used in sparsely populated and rural areas where there are few rehabilitation professionals, and high ripple effects are expected.

Key words: dysphagia, information and communication technology, pneumonia, rehabilitation

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Introduction

Aspiration pneumonia is a common disease in older patients and is associated with a decline in eating and swallowing functions due to aging and the after-effects of cerebrovascular disease[1]. Recent studies on sarcopenia and aspiration pneumonia have suggested that both the central nervous system and exacerbations of sarcopenia contribute to dysphagia[2, 3]. Murakami *et al.* reported that older adults with sarcopenia had a decreased chewing ability compared with those without sarcopenia[4]. Similarly, if there is a systemic sarcopenia, it can be inferred that meat swallowing-related muscles also suffer from muscle loss and dysfunction. Furthermore, sarcopenia in eating- and swallowing-related muscles not only occurs with systemic sarcopenia but also with eating, which may exacerbate the swallowing function[5]. Additionally, most cases of aspiration pneumonia in the elderly are diagnosed with sarcopenia[6]. Regarding the association between sarcopenia and aspiration pneumonia, Okazaki *et al.* reported that sarcopenia is a risk factor for pneumonia in older adults. Patients with aspiration pneumonia and low muscle mass have high mortality rates[7]. They suggested that the evaluation and management of sarcopenia could potentially emerge as a new strategy for the prevention and treatment of pneumonia in older patients. Notably, research on this topic has only been initiated recently. Daily measures must be implemented to address sarcope-

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nia[8]. Particularly, when a patient is hospitalized for aspiration pneumonia and sarcopenia, intensive rehabilitation of respiratory function is performed during the acute and convalescent phases. However, after discharge, many patients are repeatedly admitted and discharged from hospital without continuous rehabilitation while living at home after discharge[9]. There have been no reports of rehabilitation using Information and Communication Technology (ICT) to enable the continuous rehabilitation of patients with sarcopenia or aspiration pneumonia. Furthermore, clinical studies examining whether combined sarcopenic interventions can prevent aspiration pneumonia are lacking.

Therefore, we developed a system that uses ICT to enable the assessment and rehabilitation of patients with sarcopenia and aspiration pneumonia in a home-based environment to achieve seamless rehabilitation. This study aimed to assess the effectiveness of ICT-assisted rehabilitation in patients with sarcopenia and aspiration pneumonia.

Patients and Methods

Study design and participants

This was a single-center, open-label, randomized controlled trial conducted between July 2022 and September 2023. The participants were patients with aspiration pneumonia who were diagnosed with dysphagia using repetitive salivary swallowing and modified water-swallowing tests. Patients who were hospitalized for more than 1 week and followed up were included. A total of 120 patients were included in the study, with 60 each in the control and 60 in the intervention groups (Figure 1). Patients with cognitive impairment or missing data were excluded. Moreover, patients who could be followed up for at least 2 weeks after admission were included in the study. This study was approved by the Ethics Committee of the Nihon University Hospital (approval number: 20220704). All the participants provided informed consent to participate in the study. However, based on the Japanese Ethical Guidelines, we outlined our research in the open system of the University Hospital Medical Information Network and guaranteed the protection of personal information (registration number: UMIN000048521).

Main outcome measurement

The primary outcome was the change from baseline in the Functional Oral Intake Scale (FOIS) score at discharge. The secondary outcome was a change in Barthel Index (BI). The FOIS is a measure of nutritional performance and an indicator used by Crary *et al.* to evaluate nutrient intake[10].

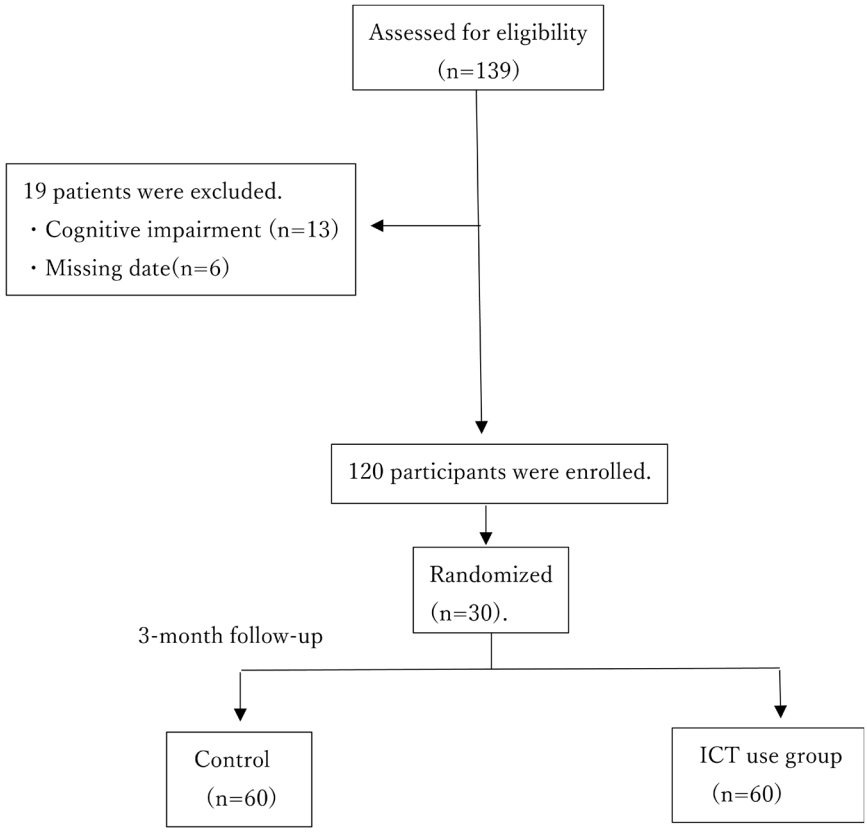

Figure 1 Study flow chart.

Additionally, the scale was expressed in seven standardized categories, ranging from tube-dependent to oral intake. Its reproducibility and validity have been verified, ranging from level 1 (no oral intake) to level 7 (normal intake). The BI is a measure of activities of daily living (ADL). It is an ordinal scale that quantifies ADL performance and evaluates 10 variables on a scale of 2–4, including feeding, transfer (bed to wheelchair and back), grooming, toilet use, bathing, mobility (on level surfaces), stairs, dressing, bowels, and bladder. Higher scores indicated a greater ability to perform basic ADL[11].

Measurement

Observations included age, sex, body mass index, nursing care level, history of respiratory disease, comorbid conditions, pneumonia severity (A-DROP), time from admission to the start of feeding, serum albumin level, Geriatric Nutritional Risk Index (GNRI), readmission status, and number of readmissions. Sarcopenia can be diagnosed by measuring grip strength and lower leg circumference. Sarcopenia was diagnosed based on the Asian Working Group for Sarcopenia 2019[12].

Swallowing function was evaluated using the repetitive salve-swallowing test (RSST)[13] and FOIS. The A-DROP scoring system classifies the severity of pneumonia based on physical examination and age. The system assessed the following variables: (1) age (≥70 years for males and ≥75 years for females); (2) blood urea nitrogen (BUN) ≥21 mg/dL or dehydration; (3) SpO_2 ≤90%; (4) confusion; and (5) systolic blood pressure ≤90 mmHg. The severity was classified into four categories (mild, moderate, severe, and very severe) based on the number of applicable variables[14]. Aspiration pneumonia risk assessment was performed using inoue-EvaluaBon AspiraBon Lung Disease (i-EALD) in the control and ICT groups[15]. The i-EALD scores the local, systemic, swallowing, and respiratory findings in the oral cavity. A total score of 6 or more indicates a high risk of aspiration pneumonia, 3–6 indicates intermediate risk, and 2 or less indicates low risk. The Charlson Comorbidity Index was used to measure comorbidity[16]. Nutritional status was evaluated using the GNRI. Furthermore, the GNRI was calculated using the formula proposed by Bouillanne *et al.*: 14.89 × serum albumin (g/dL) + {41.7 × (current body weight/ideal body weight)}[17].

ICT rehabilitation system

The ICT rehabilitation system we developed consists of an algorithm based on (1) assessment and diagnosis, (2) rehabilitation instructions, and (3) dietary instructions. The system and patient data are managed in cloud. Evaluation and diagnosis consisted of three points: I) swallowing function evaluation, II) sarcopenia diagnosis, and III) aspiration pneumonia risk assessment. Evaluation of swallowing function enabled the FOIS and RSST assessments to be performed by checking symptoms and eating patterns. The RSST also diagnosed dysphagia if the patient was unable to swallow more than three times within 30 s. The FOIS was able to diagnose the level of FOIS by checking eating patterns, and an FOIS score of 5 or less indicated the presence of dysphagia. Sarcopenia can be diagnosed using grip strength, lower leg circumference, and the 5-fold standing test.

The diagnosis of pneumonia severity can be made by simply entering the symptoms based on the i-EALD. The severity of pneumonia is scored based on local, systemic, and swallowing functions. Additionally, a total score of 2 points or less indicated a low risk of pneumonia, a score between 2 and 6 indicated an intermediate risk, and a score of 6 or more indicated a high risk. Saliva volume, oral residue, and halitosis can be scored as local findings; speech intelligibility as general findings; ADL, nutritional status, peak inspiratory flow rate, and choking during meals; and RSST as the swallowing function. An algorithm was developed to extract appropriate rehabilitation methods for each diagnosis (Figure 2). This algorithm was developed by the authors and is a flowchart-type program that can easily extract the appropriate rehabilitation program according to symptoms. This system is designed to be used not only by rehabilitation professionals but also by medical staff and patients themselves.

We systematically extracted rehabilitation programs based on the evaluations and diagnoses. Dietary guidance can also help to extract appropriate dietary patterns from algorithms for the assessment of aspiration pneumonia. Because the system inputs and evaluates the patient's symptoms and extracts a rehabilitation menu, it can be used by non-rehabilitation professionals such as nurses, registered dietitians, and care workers. It is also possible for patients to input their symptoms and select appropriate rehabilitation programs. Moreover, the assessment data can be stored using cloud management; thus, state changes can be objectively captured. An overview of the system process and monitoring screen is illustrated in Figure 3. From the functional assessment, extracting the appropriate rehabilitation menus and graph changes was possible.

System management by cloud system

System management is achieved using a cloud-based system with network servers and software accessed through the Internet. It can be accessed and used from devices such as smartphones and personal computers, as long as they have an Internet connection. Thus, the system can be used in medically underpopulated areas and for long-term care. Security was managed using double login and data encryption. The software system architecture required to use the cloud system is managed by the cloud service provider Egg, a company that provides cloud-computing services.

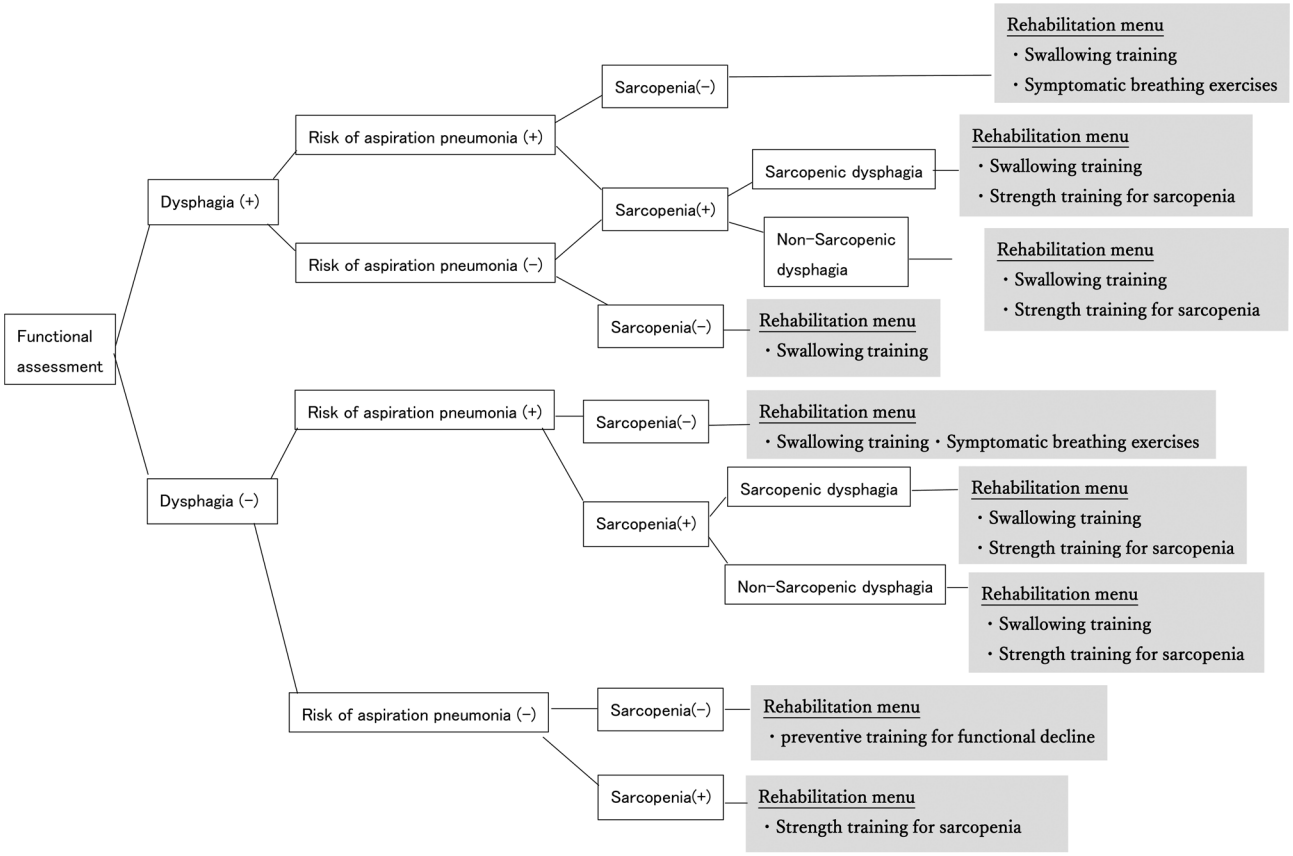

Figure 2 Algorithm for extracting optimum rehabilitation menu from functional evaluation.

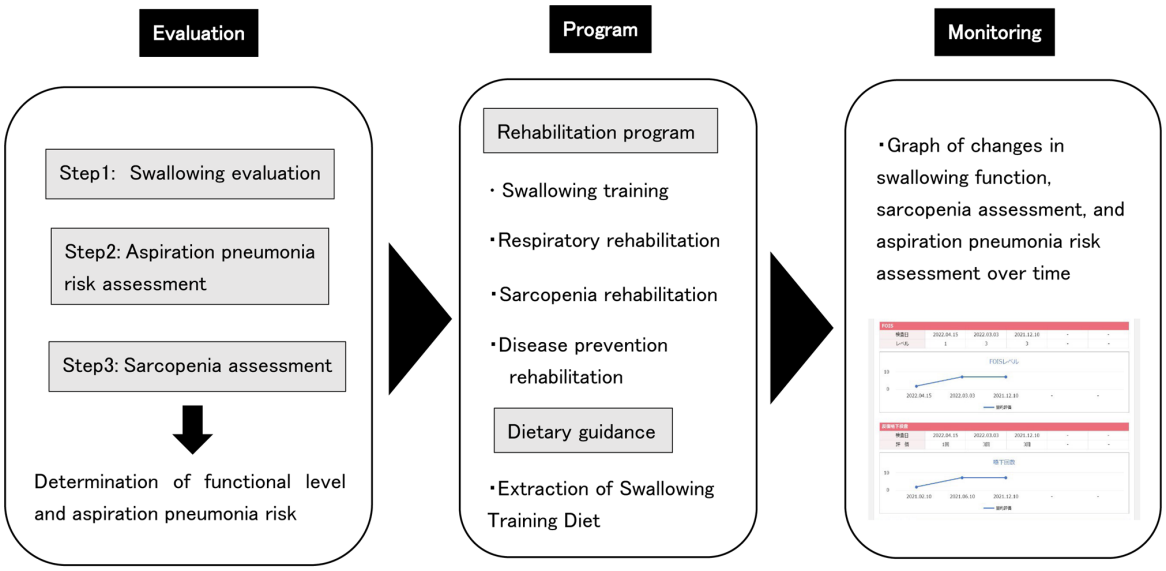

Figure 3 Overview of system processes.

Comprehensive rehabilitation programs

In the control group, physical therapists intervened and provided respiratory rehabilitation, respiratory assistance, phlegm discharge, walking, and basic movement training. Rehabilitation was performed individually for 20 min/day. In addition to the control group, the ICT-rehabilitation

group used ICT in a comprehensive rehabilitation program. In addition to swallowing function assessment, the comprehensive program included a program to create a unique algorithm for risk assessment of sarcopenia and aspiration pneumonia to enable the selection of appropriate rehabilitation and dietary patterns. The algorithm can systematically classify rehabilitation programs implemented in hospitals and rehabilitation facilities, and extract appropriate rehabilitation programs according to symptoms. One characteristic of an ICT system enables non-rehabilitation professionals to use it for rehabilitation evaluation and instruction. It is also possible to extract both systematic and original programs. Furthermore, evaluation data could be accumulated. The ICT rehabilitation group also received 20 min of functional training per day from a physical therapist. The eating and swallowing rehabilitation using ICT was performed by a physician in the rehabilitation department. Additionally, in the comprehensive rehabilitation program using ICT, the transition of the swallowing function assessment and aspiration pneumonia risk assessment are displayed as line graphs. This system also allows the diagnosis of sarcopenia and extraction of rehabilitation menus for sarcopenia. Therefore, rehabilitation of sarcopenic dysphagia should be performed.

Sample size

The sample size was calculated based on the findings of a previous study. The difference between the two groups was 0.6 points, with a standard deviation of 2.9, a significance level of 0.05, and power of detection of 0.8. This resulted in a sample size of 44 per group[18]. Considering inappropriate cases and dropouts, 60 patients were assigned to each group.

Statistical analysis

Participants were divided into two groups (ICT use and control), and survey were compared between the two groups. The primary outcome was FOIS change, and the secondary outcome was BI change. Statistical analysis was performed using the Mann–Whitney U test or unpaired t-test, and categorical variables were analyzed using the χ^2 test. Multiple regression analysis was performed using the time from admission to the FOIS score change as the dependent variable, and variables that demonstrated significant differences in the univariate analysis were used as independent variables. Furthermore, logistic regression analysis was performed with hospital readmission status as the dependent variable, whereas variables that showed significant differences in the univariate analysis were designated as independent variables. Statistical analyses were performed using the IBM-SPSS Statistics Version 25 (IBM-SPSS, Inc., Armonk, NY, USA) software, with the level of significance set at <5%.

Results

Participants' characteristics are presented in Table 1. Univariate analysis showed significant differences between the two groups in the FOIS score at discharge, FOIS change (P=0.002, P<0.001), RSST at discharge (P=0.002), and i-EARD at discharge (P=0.015). The Spearman's rank correlation results are shown in Table 2. Changes in the FOIS scores were negatively correlated with age (P< 0.05) and admission GNRI score (P< 0.01). Changes in FOIS and BI scores were positively correlated (P<0.05).

The results of the multiple linear regression analysis of FOIS changes are shown in Table 3.

ICT use positively influenced FOIS change (β=0.49, 95% confidence interval, 1.47 to 2.97 P<0.001).

The results of the multiple linear regression analysis for BI gain are shown in Table 4. ICT use positively affected as an influencing factor of BI gain (β=0.47, 95% confidence interval, 14.73 to 32.72 P<0.001).

The results of the logistic regression analysis of the factors influencing readmission are presented in Table 5. Factors influencing the presence or absence of readmission were not extracted, and the presence or absence of ICT use was not identified as an influencing factor (odds ratio=0.678, 95% confidence interval, 0.245–1.876; P =0.678).

Discussion

The findings of this controlled prospective cohort study regarding ICT rehabilitation and improvement in swallowing function are twofold. First, changes in the FOIS scores showed significantly improved results when ICT was used. Second, we found no significant improvement in sarcopenia during hospitalization in the ICT-use and control groups. To the best of our knowledge, this is the first study to demonstrate the effect of an ICT rehabilitation system on improving the swallowing function.

First, we showed that the degree of improvement in the FOIS score, an index of swallowing function, was significantly higher in the rehabilitation system that used ICT. There have been several reports on ICT rehabilitation systems. Nagatomi *et al.* reported a significant improvement in the efficacy of home-based cardiac rehabilitation in patients with heart failure[19]. Kim *et al.* described the development of rehabilitation content using ICT in patients with locomotor diseases and stroke[20]. It is an exercise rehabilitation service for patients in which hospitals and communities work together to systematically classify exercise programs conducted in hospitals and rehabilitation facilities to provide exercise rehabilitation services. However, their effectiveness has not yet been demonstrated and needs to be verified. This study examined the validity of an ICT system, in which a rehabilitation menu was extracted based on the results of the

Table 1 Clinical characteristics of the study groups at baseline

	Overall (n=120)	ICT use group (n=60)	control group (n=60)	*P*-value
Mean age ± SD, years	77.3 ± 13.9	73.7 ± 14.8	71.3 ± 11.7	0.431[a]
Sex, female, N (%)	46 (36.2)	23 (38.3)	21 (35.0)	0.528[b]
BMI ± SD (kg/m^2)	22.1 ± 3.9	22.7 ± 3.3	21.4 ± 4.3	0.061[a]
CCI (0/1/2/3/>4), N	21/58/36/5/0	11/29/18/2/0	10/29/18/3/0	0.424[b]
Presence of sarcopenia, N (%)				
On admission	111 (92.5)	55 (91.7)	56 (93.3)	0.500[b]
At discharge	110 (91.7)	56 (93.3)	57 (95.0)	0.500[b]
Severity of pneumonia				
A-drop, N (%)				
Mild	1(0.8)	0 (0)	1 (1.7)	0.004 [b]
Moderate	26(21.7)	5 (8.3)	21 (35.0)	
Severe	46(38.3)	28 (46.7)	18 (30.0)	
Very severe	47(39.2)	27 (45.0)	20 (33.3)	
Nutrition status				
GNRI on admission [IQR]	89.4 [78.4, 99.4]	93.6 [81.4, 105.1]	94.7 [76.3, 93.2]	0.367[c]
GNRI at discharge [IQR]		93.2 [82.1, 103.8]	84.2 [76.1, 92.6]	
Number of drugs on admission [IQR]	5 [4, 6]	5 [3, 6]	6 [4, 6]	0.106[c]
ADL score				
BI on admission [IQR]	25 [10, 35]	20 [10, 30]	30 [13, 40]	0.713[c]
BI at discharge [IQR]	65 [45, 80]	78 [46, 85]	57 [35, 45]	0.517 [c]
BI change [IQR]	35 [15, 55]	50 [30, 65]	25 [15, 34]	0.116 [c]
Assessment of the level of food consumption				
FOIS score at the start of feeding [IQR]	2 [0, 4]	1 [0, 3]	3 [0, 4]	0.652 [c]
FOIS score at discharge [IQR]	5 [4, 6]	5 [4, 6]	4 [0, 5]	0.002 [c]
Change in FOIS (%)				
No improvement	31(25.8)	3 (5.0)	28 (46.7)	<0.001[b]
Decline	4(3.3)	2 (3.3)	2 (3.3)	
Improvement	85(70.8)	55 (91.7)	30 (50.0)	
Swallowing function				
RSST on admission [IQR]	2 [0, 3]	2 [0, 2]	3 [0, 4]	0.002[a]
RSST at discharge [IQR]	4 [3, 4]	4 [3, 5]	4 [2, 4]	0.002[a]
Aspiration pneumonia risk assessment				
iEARD on admission [IQR]	7 [7, 8]	8 [7, 8]	7 [6, 7]	<0.001 [a]
iEARD at discharge [IQR]	6 [5, 7]	6 [5, 6]	7 [5, 7]	0.015
Rehabilitation staff intervention, n (%)				
Physical therapist	120(100)	60 (100)	60 (100)	-
Occupational therapist	16 (13.3)	7 (11.7)	9 (15.0)	0.953 [b]
Speech-language pathologist	0 (0.0)	0 (0.0)	0 (0.0)	0.309[b]
Period from admission to rehabilitation± SD (days)	2.4 ± 6.0	1.2 ± 1.4	3.98 ± 1.3	0.297 [a]
Length of stay ± SD (days)	27.7 ± 19.6	30.7 ± 17.8	24.8 ± 20.9	0.100 [a]
Readmission, n (%)	25 (20.8)	11 (18.3)	14 (23.3)	0.500[b]

[a] Student t-test, [b] χ^2 test, [c] Mann–Whitney U test. SD: standard deviation; ICT: information and communication technology; BMI: body mass index; CCI: Charlson comorbidity index; IQR: interquartile range; GNRI: geriatric nutritional risk index; ADL: activities of daily living; BI: Barthel index; FOIS: functional oral intake scale; RSST: repetitive live swallowing test; iEARD: Inoue-evaluation on aspira on lung disease.

diagnosis and evaluation of dysphagia. The results showed that the ICT rehabilitation group had a better swallowing function, demonstrating the effectiveness of the ICT system.

Second, there was no significant difference in sarcopenia between the ICT and control groups, and sarcopenia showed no significant improvement with ICT use. Moreover, this could be attributed to the fact that sarcopenia may take longer to improve than swallowing function because the participants were patients in acute-care hospitals and the hospital stay was short. Sarcopenia requires measures not only for swallowing and exercise rehabilitation but also for disease and nutritional management[21]. Therefore, achieving

Table 2 Spearman's rank correlation coefficients among the factors

	Age	CCI	GNRI	BI change	FOIS change	RSST at discharge	iEARD at discharge
Age	-	−0.056	−0.146	−0.100	−0.182*	−0.132	−0.075
CCI	-	-	−0.171	−0.025	−0.039	−0.082	0.014
GNRI	-	-	-	0.143	−0.232**	−0.299**	0.023
BI change	-	-	-	-	0.187*	0.141	−0.224*
FOIS change	-	-	-	-	-	0.227*	−0.003
RSST at discharge	-	-	-	-	-	-	−0.353**
iEARD at discharge	-	-	-	-	-	-	-

*P<0.05, **P<0.01. CCI: Charlson comorbidity index; GNRI: global leadership initiative on malnutrition; BI: Barthel index; FOIS: food intake level scale; RSST: repetitive live swallowing test; iEARD: Inoue-evaluation on aspira on lung disease.

Table 3 Multiple linear regression analysis of FOIS change

	Unstandardized		Standardized β	95% confidence interval		*P*-value
	B	SE		Lower	Upper	
Age	−0.021	0.013	−0.126	−0.047	0.005	0.117
Sex	0.555	0.357	0.118	−0.153	1.263	0.123
CCI	−0.400	0.224	−0.136	−0.844	0.044	0.077
A-drop	0.016	0.197	0.006	−0.375	0.406	0.936
GNRI	0.016	0.012	0.104	−0.008	0.040	0.196
ICT use	2.222	0.378	0.488	1.473	2.971	<0.001

FOIS: functional oral intake scale; CCI: Charlson comorbidity index; GNRI: global leadership initiative on malnutrition; ICT: information and communication technology; SE: standard error.

Table 4 Multiple linear regression analysis of the Barthel index gain

	Unstandardized		Standardized β	95% confidence interval		*P*-value
	B	SE		Lower	Upper	
Age	0.143	0.158	0.078	−0.169	0.456	0.366
Sex	1.342	4.290	0.026	−7.158	9.843	0.755
CCI	0.471	2.691	0.014	−4.859	5.802	0.861
A-drop	3.383	2.368	0.122	−1.308	8.075	0.156
GNRI	0.058	0.148	0.034	−0.234	0.350	0.695
ICT use	23.721	4.540	0.470	14.726	32.716	<0.001

CCI: Charlson comorbidity index; GNRI: global leadership initiative on malnutrition; ICT: information and communication technology; SE: standard error.

improvements within a short period may be difficult. Shen *et al.* investigated exercise for sarcopenia in older adults in a systematic review and network meta-analysis, showing high or moderate certainty that resistance exercise, with or without nutrition, and a combination of resistance exercise, aerobic exercise, and balance training, are the most effective interventions for improving the quality of life in older people with sarcopenia. The addition of nutritional interventions to exercise had a greater effect on grip strength than exercise alone, whereas other measures of physical function showed similar effects[22]. It is possible that the contents of the ICT rehabilitation program developed in this study were insufficient to manage sarcopenia in the entire body. Thus, it is necessary to examine improvements to this program to reduce sarcopenia. Additionally, ICT content should enhance the combination of resistance exercises, aerobic exercises, and balance training[23, 24].

Teixeira *et al.* developed a digital system for screening and diagnosing sarcopenia[25]. This system functions as a diagnostic tool for sarcopenia. However, no rehabilitation

Table 5 Logistic regression analysis for readmission

Variables	Odds ratio	95% confidence interval		*P*-value
		Lower	Upper	
Age	0.982	0.949	1.016	0.301
Sex	0.626	0.232	1.687	0.354
CCI	1.212	0.666	2.207	0.528
A-drop	0.763	0.463	1.258	0.289
GNRI	1.015	0.983	1.049	0.349
ICT use	0.678	0.245	1.876	0.455

CCI: Charlson comorbidity index; GNRI: global leadership initiative on malnutrition; ICT: information and communication technology.

program is required to improve sarcopenia. The developed system enables simultaneous diagnosis of sarcopenia and sarcopenic dysphagia. Moreover, it was possible to extract an optimal rehabilitation menu based on these symptoms. It is necessary to further enhance the rehabilitation menu in the future and improve the program so that it is effective even within a short period of hospitalization, such as in an acute care hospital, and to demonstrate its effectiveness in individuals living at home.

Our study had some limitations. The first is the inadequate assessment of nutritional indicators related to swallowing function and sarcopenia. It appears that there will be a program in the future to evaluate nutritional indicators to resolve these problems. Secondly, the program cited a lack of comprehensive rehabilitation for patients with sarcopenia. However, because the importance of continuous exercise has been widely discussed in many studies, it is necessary to devise a sustainable and simple program and apply it to this system.

Conclusion

We developed an ICT system for diagnosing dysphagia and sarcopenia, assessing the risk of aspiration pneumonia, and identifying the most appropriate program for each symptom similar to that used for eating and swallowing rehabilitation. The ICT rehabilitation system is useful and has demonstrated improvements in dysphagia. Moreover, this system can be used in hospitals without rehabilitation specialists, or in patients who live at home and have fewer rehabilitation opportunities, thereby preventing the progression of dysphagia and aspiration pneumonia. To improve this system, additional programmes are required to reduce the incidence of sarcopenia.

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Author contributions: Takako Nagai, Hiroshi Uei, and Kazuyoshi Nakanishi contributed equally to this study.

Disclosure: Takako Nagai, Hiroshi Uei, and Kazuyoshi Nakanishi have nothing to disclose.

Compliance with ethics guidelines: The study protocol was reviewed and approved by the Committee on Ethics, the Institutional Review Board of Nihon University Hospital, and the Ethics Committee of Nihon University Hospital (approval number 20220704). This study was conducted in accordance with the 1964 Declaration of Helsinki and its amendments.

Data availability: The datasets generated and analyzed in the current study are available from the corresponding author upon reasonable request.

Conflict of interest: The authors declare no conflict of interest.

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