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A Smartphone Application as a Telemedicine Tool for Stroke Care Management

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Abstract

Since smartphone applications are revolutionizing telemedicine, a new application specifically for stroke care (JOIN) was designed. Addition of the JOIN smartphone application to the stroke treatment workflow in our hospital was assessed. JOIN has key functions that may improve the care of stroke patients, including the ability to (1) exchange information such as patient data and medical images in real-time throughout the entire process of patient management; (2) track each step of the protocol from door to discharge; and (3) facilitate real-time interaction of all team members via text, audio, and a video chat system. Two periods, 2.7 years before the implementation of JOIN (Pre-JOIN) with 37 patients and 2.2 years after (Post-JOIN) with 54 patients, were compared, and the workflow for all 91 patients who had a cerebral infarction and were treated with tissue plasminogen activator (tPA) and/or thrombectomy between October 2012 and July 2017 was reviewed. There were noticeable reductions in overall patient management time, including times for door-to-imaging, starting tPA treatment, and endovascular intervention with JOIN. Staff members were unanimously satisfied with JOIN, due to the increased efficiency of information exchange and the ability for real-time discussions with different professionals when needed. No significant changes in patient outcomes (as assessed by modified Rankin Scale [mRS] scores) at 3 months and in the total cost for the treatment were observed. A smartphone-based application with the capability of sharing information instantaneously among healthcare professionals facilitated time-sensitive, acute care of ischemic stroke patients.

Keywords: telemedicine, smartphone application, cost-effectiveness, information and communications technology, diagnosis procedure combination

Introduction

Telemedicine, the use of information and communication technologies for healthcare,[1)] may be especially useful when specific medical decisions need to be made quickly, as in acute ischemic stroke, where physicians have only a limited time from stroke onset to starting treatment. Studies have shown that telemedicine can be effective in the area of acute stroke management.[2,3)]

The American Heart Association (AHA) guidelines for the early treatment of acute ischemic cerebrovascular disease include new recommendations for telemedicine and teleradiology.[4–6)] Several studies on the utility of telemedicine for acute care of ischemic stroke patients have also been conducted in Japan, and its use was added to the Japanese stroke guidelines in 2015.[7)]

Compared to the existing concept of "telemedicine"—connectivity between two hospitals (a

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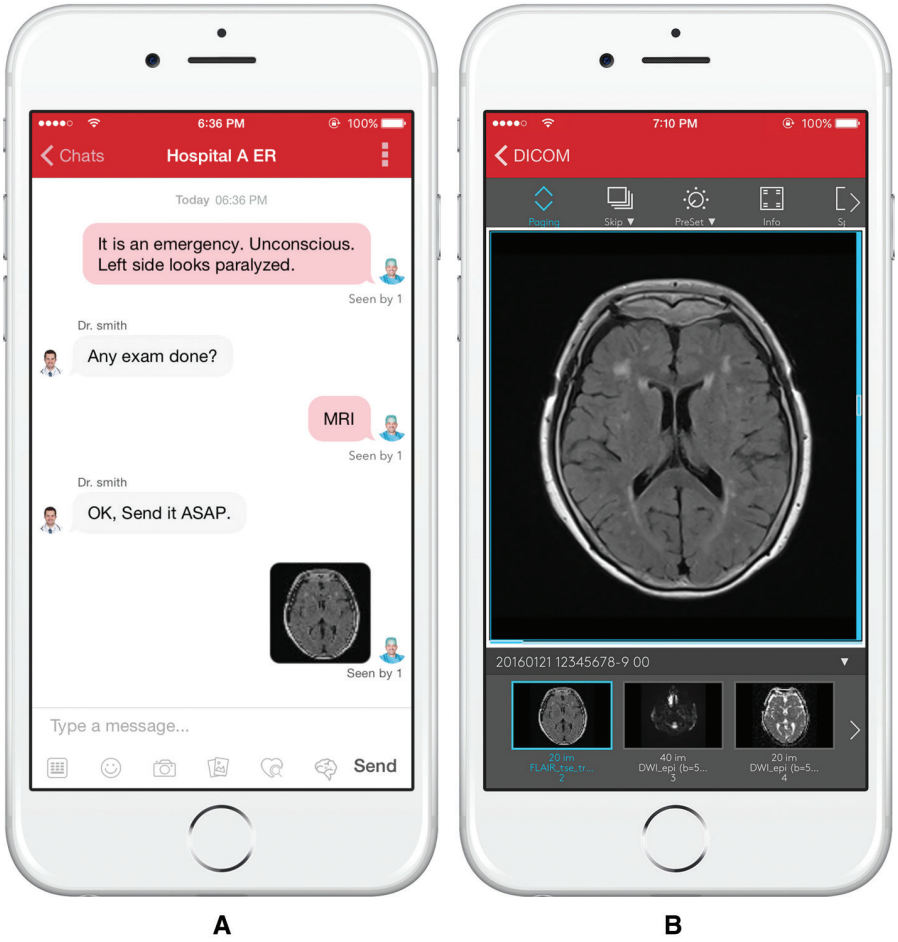

Fig. 1 Sample images of the JOIN software in use. Communication regarding a patient (left) and sharing of DICOM data (right).

hub-and-spoke model), where a specialized doctor from the "hub" hospital consults regarding a patient in the "spoke" hospital—a smartphone application envisions connections between multiple doctors within a hospital (in-hospital) or between hospitals (inter-hospital), potentially improving diagnostic and treatment capabilities.

JOIN[8–11] (Fig. 1) is a communication application for new-generation smartphones that works through current high-speed networks (LTE, 4G). It is an evolution of "i-Stroke," Japan's first teleradiology diagnostic application for smartphones developed in 2008.[12] Users of JOIN can share information and images in a DICOM format on the new high-resolution screens of smartphones anytime and anywhere. The main concept of JOIN is communication between healthcare professionals, similar to social networking services (SNSs) such as WhatsApp, LINE, and iMessage. SNSs are now essentially ubiquitous. A recent study indicated that nearly two-thirds of American adults (65%) use social networking sites.[13] Capurro et al.[14] investigated the use of such sites as an interface for healthcare and showed that they could positively impact telemedicine with almost no learning curve for the end users.

As an in-hospital telemedicine application for healthcare professionals involved in the care of acute ischemic stroke patients, JOIN should enhance the communication and information flow among medical professionals, as well as expedite and improve decision-making, resulting in better patient outcomes and lower overall costs.

In the present study, the clinical benefits of JOIN as a telemedicine tool were evaluated, comparing data before and after its introduction as part of routine stroke management.

Materials and Methods

Standard protocol approvals, registrations, and patient consents

This retrospective study was approved by the Jikei University Clinical Research Ethics Committee (26-122(7627)), and the requirement for consent was

waived. Patients were given the option of opting-out based on information provided on a publically available website.

Use of JOIN as a communication application for healthcare professionals

JOIN is activated as soon as the emergency department is informed that a potential stroke patient is expected. With the standard notification function available in the application, relevant personnel are alerted, initial diagnostic and therapeutic orders are given, and if necessary, senior staff can be consulted. DICOM images (e.g., computed tomography [CT], magnetic resonance imaging [MRI]) can be acquired and shared via the smartphone interface, and the decisions with the related images can be evaluated. JOIN's video-chat function also allows additional evaluation of the patient. For instance, clinical signs can be seen by senior consulting staff even when they are not in the hospital. Treatment with tissue plasminogen activator (tPA) can be performed, and other treatment decisions such as an interventional procedure (e.g., thrombectomy) can be discussed. In the event an interventional procedure is performed, it can be followed on streaming video images transmitted via JOIN to the off-site consulting staff. Final orders can be decided by consensus among team members before admission of the patient to the neurocritical unit.

JOIN follows required security protocols, so none of the displayed data are stored in the smartphone (Fig. 1). Furthermore, after completing a communication session, none of the information remains stored on the smartphone.

Staff structure in the research field and decision-making policy using JOIN

In this study, cases using JOIN only in our hospital were analyzed. In our stroke medical care system, one emergency on-call physician is available through the day and night for acute stroke, and in addition, doctors and nurses in the emergency department provide support in the medical care.

Emergency duty and shift work are handled by each clinical department, and the doctors in charge of stroke treatment vary from the fifth year of doctors to senior specialists. Only some of the physicians are specialized in stroke, and as a general rule, decision-making prioritizes patient bed-side decisions, but remote consultants may send advice on JOIN to administer/cancel a treatment. The decision to implement endovascular treatment is handled by contacting an endovascular neurosurgeon by JOIN. JOIN can send information to a large number of people at the same time, including paramedics.

Evaluating the effectiveness of a more efficient communication application for healthcare professionals

A total of 91 patients who had a cerebral infarction and were treated with tPA and/or received endovascular treatment (specifically thrombectomy) between October 2012 and July 2017 were reviewed. The patients were divided into two groups based on the following period: before May 1, 2015 (Pre-JOIN) and after the establishment of a stroke unit and the start of routine use of JOIN (Post-JOIN).

In all, 37 patients were treated during the Pre-JOIN and 54 during the Post-JOIN time periods. They were part of the initial cohort of 897 patients admitted to the hospital with a diagnosis of acute cerebral ischemia (Table 1). The same team members participated in the management of stroke patients during both periods.

Key time milestones in the stroke workflow management, such as hospital arrival to CT/MRI, to the start of the tPA infusion, and to the start of endovascular treatment (groin puncture), were tracked.

Patients were evaluated at follow-up 3 months after discharge, and their modified Rankin Scale (mRS) scores were recorded. The patients who showed a worsening of their mRS scores were also compared with those having either an improvement or no change in their mRS scores.

Statistical analysis

The chi-squared test was used to analyze continuous variables. Data that did not show a normal distribution were considered non-parametric and were analyzed using the Mann–Whitney U test. However, data showing a normal distribution (considered a parametric group) were carefully evaluated and analyzed using the unpaired *t*-test when they showed equal variance. Data that did not show equal variance were evaluated using Welch's *t*-test. P values <0.05 were considered significant. All statistical analyses were performed using STATA 13.1 (STATA Corp, College Station, TX, USA).

Results

Characteristics of the patients treated in this study

The mean age ± standard deviation of the 91 patients was 68.9 ± 22.0 years, 71.8 ± 10.8 years for those treated during Pre-JOIN, and 67.0 ± 15.2 years for those treated during Post-JOIN.

There was a significant difference in age, coinciding with the inauguration of a specialized stroke care unit (SCU) in our hospital and the increased referrals of elderly patients. Although no changes were made to the management protocols, there was

Table 1 Pre-JOIN and Post-JOIN breakdown of patients admitted to the hospital with a diagnosis of acute cerebral ischemia

	Pre-JOIN	Post-JOIN	Total Cases
Cases reviewed in this study	37	54	91
Under medical management and observation	366	392	758
Transferred to another institution	29	19	48
Total number in the initial cohort	432	465	897

Table 2 General characteristics of the Pre-JOIN and Post-JOIN groups

	Total (%)	Pre-JOIN (%)	Post-JOIN (%)	P value
Sex (female)	29 (31.87)	14 (37.84)	15 (27.78)	0.31
tPA	67 (73.63)	29 (78.38)	38 (70.37)	0.39
Endovascular treatment	45 (49.45)	18 (48.65)	27 (50.00)	0.90

tPA: tissue plasminogen activator.

an increase in the number of cases of acute stroke treated with tPA and/or thrombectomy compared to the Pre-JOIN time period.

There was no significant difference in the sex of the patients between Pre- and Post-JOIN. The applied management protocols, including tPA and/or endovascular treatment, demonstrated comparable rates for Pre-JOIN and Post-JOIN: 78.4% vs. 70.4%, respectively, for tPA and 48.6% vs. 50.0%, respectively, for endovascular interventions (Table 2).

Criteria to quantify the effects of JOIN during management of stroke patients

The time intervals from hospital arrival to the beginning of the imaging investigations, to tPA treatment initiation, and, finally, to endovascular treatment initiation (Table 3) were examined.

The mean time from hospital arrival to the beginning of the imaging investigations tended to be reduced from 36.4 to 27.3 min ($P < 0.1$). Reductions in the mean times to initiation of tPA (from 81.0 to 64.3 min, $P = 0.003$) and to the initiation of endovascular treatment (from 140.9 to 109.9 min, $P = 0.01$) were observed.

There was also a reduction in the mean total time of treatment from 98.8 to 81.1 min. However, this result requires further analysis, since the "total time" incorporates other stages of the management protocol that were not part of this study. The total treatment time also includes patients who were not part of this study (i.e., patients who underwent thrombectomy without tPA), which creates an extra variable for the total number of observed patients.

Along with the time intervals, the clinical results of stroke treatment were also compared by examining the proportions of those who had a lower mRS score and those who had either an improvement or no change in their mRS score. At 3 months after discharge, there were no significant differences in the two outcome categories, although a tendency toward an improved outcome was observed in the Post-JOIN group (Table 4).

Finally, a comparison of the total treatment cost in relation to the introduction of JOIN did not show any significant increases in the Post-JOIN time period (Table 5).

Discussion

Telemedicine needs and issues with existing systems

The problem with modern medicine is that despite the advancement of medical technology, the quality of diagnoses and treatment can vary between locations depending on the available equipment and skilled staff, which tend to be more concentrated in larger cities. One possible solution for overcoming the unavailability of specialized staff and equipment is telemedicine. The use of telemedicine makes it possible to overcome the shortage of specialized staffs and equipment. With the earlier start of diagnosis and treatment, particularly tPA treatment, the need for communication between emergency services and stroke teams is increasing. There have been many reports on stroke telemedicine to date, but the biggest benefits of the JOIN system are the cost and learning curve. This research report intends to clarify the advantages of the JOIN system for the stroke management team based on a retrospective analysis.

To overcome the challenge of standardizing the quality of diagnosis and decision-making for patients

Table 3 Significant differences between the mean, standard deviation, number, and median of CT/MRI start times, tPA drip start times, and neurointerventional puncture times for the two periods: Pre-JOIN and Post-JOIN

	Total				Pre-JOIN				Post-JOIN				Comparison
													P value
	Mean	SD	Median	N	Mean	SD	Median	N	Mean	SD	Median	N	Statistical method: Mann–Whitney U test
CT/MRI start time (min)	31.01	22.00	25	91	36.43	26.60	25	37	27.30	17.51	22	54	0.1
IV tPA start time (min)	71.55	25.57	67	67	81.00	24.89	75	29	64.34	17.80	63	38	0.003
Puncture time (min)	122.31	54.11	115	45	140.89	56.16	128.5	18	109.93	49.95	96	27	0.01
Treatment time (min)	88.30	48.49	73	91	98.84	52.93	80	37	81.07	44.26	67.5	54	0.02
Age (y)	68.92	13.75	70	91	71.76	10.80	70	37	66.98	15.24	70.5	54	0.24

CT: computed tomography, MRI: magnetic resonance imaging, SD: standard deviation, tPA: tissue plasminogen activator.

regardless of location and time, which is the prime objective of telemedicine, the hardware and infrastructure for this technology must be downsized and made more affordable. One of the issues to be solved is cost. The current telemedicine systems are technologically sophisticated, taking advantage of the excellent data communication infrastructures, such as fiberoptic transmission and 4K quality video systems, under reliably secure environments. Due to their substantial cost, however, these telemedicine systems are currently implemented in locations connecting larger comprehensive stroke centers and mid-size hospitals, where the number of patients justifies the expense. Since the JOIN system uses a general smartphone as a communication system, it does not require advanced communication technology, so it has the advantage of low initial installation costs. It makes telemedicine systems smaller and more affordable for smaller hospitals and clinics.

Another advantage of the JOIN system is that users can learn to use it quickly. The JOIN system has low maintenance costs and no complex implementation processes. Furthermore, there were no required hours of training. Since the JOIN system uses a smartphone with which users are familiar, it can be installed in medical facilities without any special training. Given these benefits, the JOIN system, an application for management of patients requiring acute care such as ischemic stroke patients, could bring to fruition the much sought after "anytime, anywhere" treatment for these types of patients.

Review of results and comparison with previous research

The application used in this study, JOIN, is the first smartphone application to be certified as a "medical device" by the Ministry of Health, Labour and Welfare of Japan. The advantage of using medical communication applications such as JOIN is that DICOM images can be shared and evaluated as soon as they are ready on common chat room interfaces, thereby facilitating real-time discussions by medical teams. Legacy telemedicine systems including some mobile apps were mainly focused on the DICOM viewer and/or the video streaming function itself.[12,15] Smooth communication with push-type notification and interaction of members of the medical team with different levels of experience and backgrounds increases the accuracy of diagnoses and may lead to better patient outcomes.

Evaluation of patient outcomes at 3 months after admission in the present study tended to show a positive effect from the introduction of JOIN, but the results are not conclusive due to the limited sample size. Since there were no differences in the

Table 4 Pre-JOIN and Post-JOIN comparison of patient outcomes

Three-month follow-up	Total	Pre-JOIN	Post-JOIN	P value
mRS score (0–2)	53 (58.24)	17 (45.95)	36 (66.67)	0.049
mRS score improved or stable	44 (48.35)	16 (43.24)	28 (51.85)	0.42

mRS: modified Rankin Scale.

management protocols during the study period, we considered the effect of JOIN to be less affected by other factors, such as the learning curves of the medical process or the establishment of an SCU. The effect of the increased number of referrals (increased load) comparing between the Pre-JOIN and Post-JOIN periods was also not taken into consideration.

Data reported by Lees et al.[16] showed a beneficial effect on the mRS score (0–1) in 43.6% of the patients when thrombolysis was performed within 270 min after stroke onset. These data are in accordance with the findings showing that, if the time to treatment is shortened by 1 h, the number of patients with mRS scores of 0–1 would increase 1.3-fold. The latest AHA guidelines provide a strong recommendation for a "door to needle" time of 60 min or less, with level 1 evidence.[5]

Telemedicine costs and revenues

The results of the present study also showed that the use of JOIN in our hospital was associated with higher, although not significantly, overall medical expenses, despite previous studies reporting the usefulness of information and communication technologies in terms of medical cost-effectiveness.[17,18]

In fact, assessing the cost related to treatment may require a completely new study design, since better efficiency may not translate into direct reductions in cost. For instance, better communication may result in the use of tPA as the patient timeline falls within the treatment window of 4.5 h, which might not happen if the communication process is inefficient. This would likely increase the chances for a better outcome, but the tPA expense would then be included in the cost.

Cost-effectiveness should be assessed along with potential revenue when considering the benefits of a system such as JOIN, since telemedicine in stroke care is used for both in-hospital communication and inter-hospital communication, with the latter impacting the number of patients referred from remote locations.

The revenue and cost structure will also differ depending on the healthcare system and the method of reimbursement, so future research will need to be adapted to the specific region and/or country where it will be performed.

Limitations

The application of a telemedicine system strongly impacted the daily routine of healthcare professionals managing stroke patients; however, the "metrics" of patient outcomes and economic criteria are predominantly affected by medical treatment methods and healthcare management systems. Aside from its effect on timing, JOIN, as a smartphone-based system, does not interfere with the contents of the management protocol and the cost of its discrete steps. However, whereas the effect of using JOIN on staff performance was clear, the direct effect on patients requires further investigation. Broader implementation with a larger number of patients may provide a clearer effect on patient outcomes in cases in which the follow-up period in case-matched patients has been fully considered. That will remove the potential bias in evaluating medical teams with more or less effective performance, including timeline parameters.

Since telemedicine systems will likely be introduced in a greater number of hospitals over time, the most crucial points for the future development of telemedicine in the field of stroke management are randomized trials and cost analyses. However, ethical issues may arise in randomized trials involving groups in which practical and useful telemedicine is applied for some patients, but not for all of them. Furthermore, since randomization will be difficult, we may need to consider the existing level of evidence regarding the effectiveness of telemedicine for stroke care management.

Conclusions

A comparative study of two groups with and without the routine use of JOIN, a software application for smartphone-based telemedicine in stroke management, demonstrated reduced time periods for the key aspects of acute patient management, with some improvement in outcomes and without negative effects on the treatment cost. The use of JOIN also facilitated the practical performance of stroke management, expediting decision-making, as well as the exchange of data and opinions.

Table 5 Statistical evaluation of medical costs for endovascular and tPA treatments, as well as overall medical costs, Pre-JOIN and Post-JOIN

	Total (N = 91)			Pre-JOIN (N = 37)			Post-JOIN (N = 54)			Comparison
	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	P value
										Statistical method: Mann–Whitney U test
Total medical costs (yen)	2920184	2382000	2282020	2666611	1708433	2060300	3093928	2752595	2441025	0.33
Medical costs/day (yen)	120310.1	69215.92	101611	126764.8	95247.74	88749	115887.5	43865.43	113471.5	0.26
Duration of hospital stay (days)	29.97	26.14	22	27.41	19.55	23	30.04	29.97	22	0.65
tPA treatments	Total (N = 57)			Pre-JOIN (N = 29)			Post-JOIN (N = 38)			Comparison
	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	P value
										Statistical method: Mann–Whitney U test
Total medical costs (yen)	2331618	1392378	1802460	2443843	1800676	1794590	2245973	993535.2	1987440	0.47
Medical costs/day (yen)	120480.1	76712.74	102584	130190	103498.9	88749	113070	47545.87	113472	0.60
Duration of hospital stay (days)	23.69	16.27	19	24.93	19.89	17	22.74	13.07	19	0.76
Endovascular treatment	Total (N = 45)			Pre-JOIN (N = 18)			Post-JOIN (N = 27)			Comparison
	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	P value
										Statistical method: Mann–Whitney U test
Total medical costs (yen)	4059960	2772564	3690830	3487725	1327551	3539585	4441451	3388036	3692740	0.25
Medical costs/day (yen)	141516.4	8175.91	119220	148345.7	118700	95283.5	136963.5	45220.09	141866	0.21
Duration of hospital stay (days)	35.82	31.90	29	32.33	16.60	32	38.15	39.09	26	0.91

SD: standard deviation, tPA: tissue plasminogen activator.

In conclusion, a quantitative evaluation of the practical benefits of any telemedicine system, including JOIN, is a very challenging task. The main reason is the multiplicity of factors and variables that influence the course and treatment outcome of ischemic stroke. The complex interactions of these factors and variables may exert a much stronger impact on clinical outcomes and economic metrics than the communication system itself, which is used only for coordination of patient management.

Additional studies of several aspects of the advantages of using telemedicine in the management of stroke care are needed, including, but not limited to, patient outcomes, performance of stroke care management, revenue and associated costs, and the standardization of the quality of stroke diagnosis and care.

Conflicts of Interest Disclosure

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