Clinical Efficacy of Telemedicine in Emergency Radiotherapy for Malignant Spinal Cord Compression

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The authors developed a Telecommunication-HElped Radiotherapy Planning and Information SysTem (THERAPIST), then estimated its clinical benefit in radiotherapy in district hospitals where consultation with the university hospital was required. The system consists of a personal computer with an image scanner and a digital camera, set up in district hospitals and directly connected via ISDN to an image server, and a treatment planning device set up in a university hospital. Image data and consultative reports are sent to the server. Radiation oncologists at the university hospital determine a treatment schedule and verify actual treatment fields. From 1998 to 1999, 12 patients with malignant spinal cord compression (MSCC) were treated by emergency radiotherapy with the help of this system. Image quality, transmission time, and cost benefit also were satisfactory for clinical use. The mean time between the onset of symptoms and the start of radiotherapy was reduced significantly from 7.1 days to 0.8 days ($P < .05$) by the introduction of the system. Five of 6 nonambulant patients became ambulant after the introduction of THERAPIST compared with 2 of 8 before the introduction of THERAPIST. The treatment outcome was significantly better after the introduction of the system ($P < .05$), and suggested to be beyond the international standard. The telecommunication-helped radiotherapy and information system was useful in emergency radiotherapy in district hospitals for patients with MSCC for whom consultation with experienced radiation oncologists at a university hospital was required.

KEY WORDS: telemedicine, teleradiology, radiotherapy, emergency, malignant spinal cord compression.

TREATMENT PLANNING of radiotherapy is a complicated process in which well-rounded knowledge in clinical oncology, anatomy, tumor spread, and each patient's condition is required of physicians. It is ideal for cancer patients to be seen by cancer specialists who fulfill requirement. However, there can be a situation in which patients do not have direct access to such specialists because of various difficult situations, such as living in isolated communities, developing countries, under heavy weather, or in an emergency at midnight. In such circumstances, radiotherapy can be performed by a radiation oncologist who is qualified in terms of knowledge but has less experience. Some hospitals may not have a medical physicist for quality assurance. Even in advanced countries, proper treatments for rare diseases often require guidance from specialists in university hospitals. Teleradiology is expected to be useful in such circumstances because it has been proven so in diagnostic radiology.[1-3] To assist radiotherapy in the difficult circumstances, we have developed a telecommunication-helped radiotherapy planning and information system (THERAPIST), and have been evaluating the efficacy of system since 1997.[4,5]

Malignant spinal cord compression (MSCC) is known to be an oncologic emergency. The treatment outcome of patients with MSCC depends on the time between the onset of symptoms and the start of radiotherapy.[6-8] If radiotherapy is not performed within 24 to 48 hours after the onset of MSCC, most patients cannot recover from paralysis. A portion of the patients may require surgical decompression. However, even in hospitals in which radiotherapy equipment is available, experienced neurologists, neuroradiologists, radiation oncologists, and surgeons may not all be on staff. In such cases, patients may not be able to receive emergency radiotherapy within the appropriate time period.

Telecommunications may be helpful to improve this situation. Here, we report our prospective trial using THERAPIST in the treatment of MSCC in a district hospital.

MATERIALS AND METHODS

The THERAPIST consists of computer terminals with an image scanner, 2 image monitors, and a digital camera set up in district hospitals and directly connected via ISDN-64 to an image server with 2 image monitors, and a treatment planning system set up in the university hospital (Fig 1) Windows NT4.0 (Microsoft Co.) is used as the operation system. Various types of computed tomography (CT), magnetic resonance imaging

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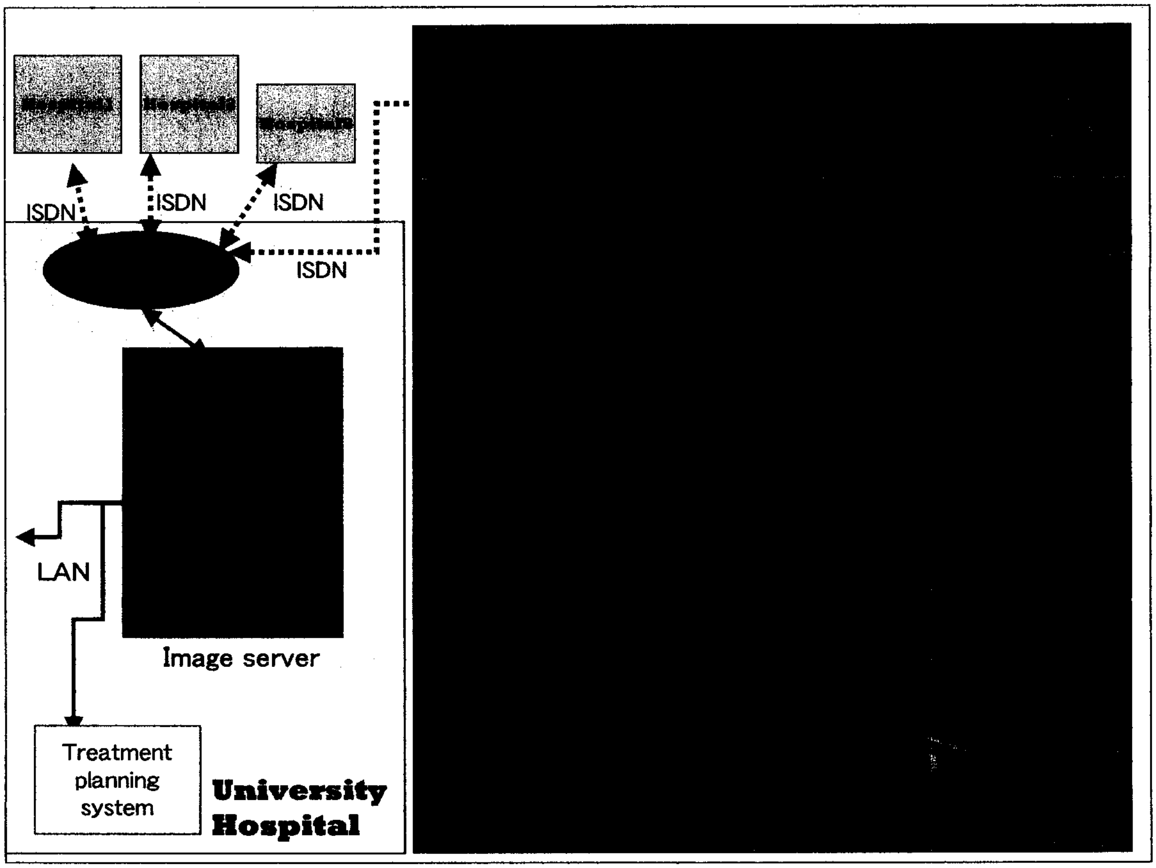

Fig 1. The system configurations of THERAPIST. The system consists of computer terminals with an image scanner, 2 image monitors, and an OCD camera set up in district hospitals and directly connected via ISDN-64 to an image server with 2 image monitors and a treatment planning system set up in the university hospital. We have 2 other district hospitals, which are connected by ISDN as the 4 hospitals in this Figure.

(MRI), x-ray devices, and Gamma cameras were used for diagnostic purposes with remote consultation using THERAPIST in each peripheral hospital. However, all images were digitized by the same image scanner (ES-8000, EPSON Co, Tokyo, Japan) in this study. For emergent radiotherapy, we used a treatment simulation CT (Xviger with CT port; Toshiba, Tokyo, Japan) and ^{60}Co-treatment device (RCR-120; Toshiba) in the peripheral hospital. Each image is digitized by a 250-dpi image scanner and compressed by JPEG (Joint Photographic Experts Group) 10:1 compression, lossy, and sent to the server. Data of CT can be transferred for dose calculation. Each CT or MRI file contains 12 images, which were digitized by image scanner. As of October 2000, 6 district hospitals were connected to the server in the university hospital.

Patients with MSCC are treated according to the following procedure. (1) Informed consent about consultation: A radiation oncologist or referring physician in the district hospital examines the patient. After obtaining the informed consent of the patient, the attending oncologist or physician consults with the university hospital to discuss suitable treatment. CT, MRI (0.5T), bone x-ray, bone scintigram, a consultative report, and digital photographs of the patient under physical examinations are sent to the server. When a doctor in a remote hospital needs to consult with the radiation oncologists in the university hospital, they call the radiation oncologists using a telephone or beeper and begin the session of telecommunication. E-mail communication was used for nonemergency cases. (2) Treatment planning: The referral doctor explains the results of the consultation to the patient and obtains the patient's informed consent to perform the treatment. CT treatment simulation is performed via telecommunication. The radiation oncology team in the university hospital performs treatment planning using the CT images that have been sent from the district hospital. Dose distribution is calculated using the 3-dimensional dose calculation system in the university hospital. (3) Treatment verification: A portal image is taken at the district hospital using megavoltage treatment x-ray and sent via telecommunication to the university hospital for treatment verification. A treatment simulation image, or a digitally reconstructed radiograph (DRR) from treatment simulation CT images also is sent for comparison. (4) Actual treatment in the district hospital: After the acceptance of verification film by the radiation oncologist in the university hospital, the patient receives emergency radiotherapy in the district hospital. Radiotherapy is scheduled to give 25Gy in 5 fractions using a posterior single field in principle. (5) Follow-up and evaluation of treatment outcome: Follow-up examinations are performed regularly in the district hospital after the treatment. The patients' photograph, follow-up CT or MRI and clinical records were sent to the server in the university hospital for follow-up and evaluation of the patients' condition (Fig 2).

In this study, the transmission time for each image, setup time to prepare the patient in the treatment room, overall treatment time, and workload for the radiation oncology staff in the university hospital was measured in each case.

From 1998 to 1999, 4,012 images from 1,073 patients with various diseases were sent for remote consultation from one district hospital. The system was used for treatment verification in 1,063 cases, for confirmation of treatment policy in 3 cases, for consult of difficult diagnosis for radiotherapy in 10 cases, for assessment of the quality of life after the palliative radiotherapy in 16 cases, for quality assurance (QA) of multiinstitutional study in 2 cases, and for emergent radiotherapy in 14 cases. Fourteen (1.3%) of the 1,073 patients were referred to the university hospital as oncologic emergencies (Table1). Twelve patients with MSCC, one with superior vena caval obstruction (SVCO) syndrome, and one with bronchial obstruction were included among these patients. The 12 patients with MSCC are the subjects of this study. The patient characteristics are shown in Table 2. All patients were diagnosed by CT or MRI examination to have MSCC. All had severe pain and neurologic symptoms of involved nerve roots. Six of the 12 patients were nonambulant before the treatment, and the remaining 6 patients were ambulant. Urinary dysfunction had been shown in 4 patients. One patient was treated with THERAPIST twice in 2 years as a result of having different levels of MSCC.

The efficiency of THERAPIST was evaluated by comparing the clinical outcome of patients for whom it was used with that of patients treated before the introduction of THERAPIST in the same district Seventeen patients with MSCC were treated in the same district hospital during the 4 years (1994 through 1997) before the introduction of THERAPIST. Nine of 17 patients were nonambulant before the treatment. All of these patients were treated with radiotherapy in the same hospital with the same radiation dose and fractions as that given to patients for whom the THERAPIST was used. During the study period (1994 through 1999), there is no change in imaging equipments, treatment device, treatment planning system, referring doctors, and patient population in this peripheral hospital. According to the introduction of THERAPIST, the referring doctors understood the importance of emergent radiotherapy for MSCC patients, and they came to refer the patients more easily using this system. Therefore, in spite of no change in the patient population, the number of referring patients with MSCC increased 4.2 to 8.0 per year after the introduction of THERAPIST.

Cost benefit was calculated using a clinical model assuming that one patient with MSCC was treated in the district hospital with or without THERAPIST. The total running cost of the system was calculated by the initial investment, the maintenance cost, the transmission cost, and the cost of magnetic memory. For this calculation, 10 branch hospitals were assumed to be connected to the server in the university hospital.

We used 1-tailed t test to compare the values. The numeric values are stated as means ± SD.

RESULTS

Time Study

For one patient, 20 to 38 diagnostic CT images, 38 to 50 diagnostic MRI images, 1 bone scintigram, and 2 bone x-rays were sent to the server for consultation. For treatment planning and verification, 1 portal image, 1 DRR, and 12 to 24 planning CT images were sent to the server. For diagnostic purposes, a set of 12 CT images or 12 MRI images were filmed on one film, and that film was scanned by a film scanner. The file size of the film with the 12 CT/MR images was 100 to 120 kB. Other images were sent to the server separately. The file sizes were 300 to 450 kB for one bone scintigram, 150 to 240 kB for one chest x-ray, 150 to 240 kB for one portal image, and 130 to 240 kB for one DRR. Transmission time was 30 to 49 seconds for one CT/MRI film (ie, 12 images) and for one DRR, 102 to 180 seconds for one bone scintigram, and 70 to 82 seconds for one portal image. The mean total image transmission time for 1 patient was 532 ± 120 seconds, ranging from 230 seconds to 777 seconds. The mean connecting time of ISDN was 14.5 ± 1.8 minutes, ranging from 10.5 to 17.2 minutes for one patient. The time between the setup of the patient on the treatment couch to the start of radiotherapy ranged from 10 to 30 minutes. The mean workload of the radiation oncologists in the central hospital was 49 ± 12 minutes, ranging from 40 to 64 minutes for one emergency radiotherapy.

Clinical Outcome

Using THERAPIST, radiotherapy was performed within 24 hours after the onset of MSCC in 11 (92%) of 12 patients. All 6 ambulant patients remained ambulant after the treatment. Five (83%) of the 6 nonambulant patients became ambulant after the treatment. The remaining patient, who was treated 48 hours after onset, did not recover from paraplegia after the treatment. Pain was reduced in all patients. Urologic symptoms disappeared in 3 of 4 patients. The mean follow-up time was 18 months (8 to 24 months). Actuarial survival rate of the MSCC patients was 72% at 1 year and 42% at 2 years. The hospitalization time was 1 to 3 months (mean, 2.3 months).

Before the introduction of THERAPIST, 3 (17.6%) of 17 patients were treated within 24 hours

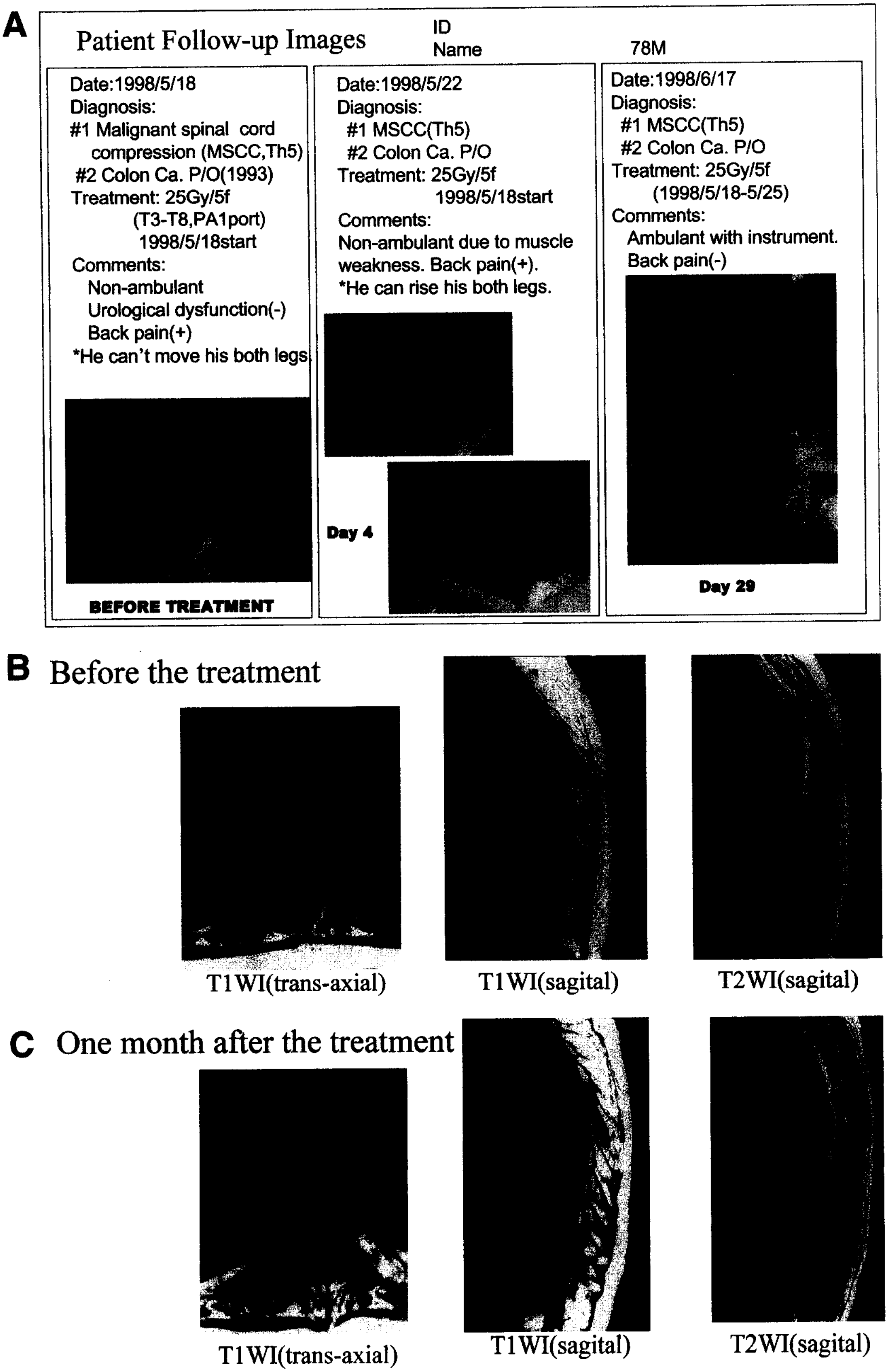

Fig 2. The follow-up images that were sent to the server in the university hospital from the district hospital; (A) Patient's photographs in clinical examinations, (B) MRI image before the treatment, and (C) MRI image after the treatment.

Table 1. Remote Consultation for Emergency Radiotherapy Using the THERAPIST (1998-1999)

Consultation Purpose	No. of Cases	Transferred Images	No. of Image Files	File Size* (KB/file)	Transferred Data Size per Case
Malignant spinal cord compression (MSCC)	12	DRR & portal images	26	105KB	
		CT and MRI†	33	120KB	
		Bone scintigram	13	150KB	801KB/case
		Patient's photograph	30	83KB	
		X-P treatment plan	12	102KB	
		Treatment planning CT	12	125KB	
		Document‡ (image file)	12	116KB	
Superior vena caval obstruction (SVCO) syndrome	1	DRR & portal images	2	150KB	
		CT and MRI†	2	120KB	
		Patient's photograph	1	78KB	663KB/case
		X-P treatment plan	1	105KB	
		Treatment planning CT	1	130KB	
		Document‡ (image file)	1	80KB	
Bronchial obstruction with lung cancer	1	DRR & portal images	2	108KB	
		CT and MRI†	1	122KB	
		Patient's photograph	1	80KB	662KB/case
		X-P treatment plan	1	120KB	
		Treatment planning CT	1	122KB	
		Document‡ (image file)	1	110KB	
Total	14		165	111.8 KB/file	

*The "file size" was calculated by average of number of bytes per one file in all image files.
†Each CT or MRI file contains 12 images, which was digitized by image scanner.
‡The "document" file was made by digitizing the image of handwriting with some contents; letters from referring doctors, informed consent, medical records and results of physical examinations.

after the onset of MSCC. Nine ambulant patients were all ambulant, but only 2 (25%) of 8 nonambulant patients became ambulant after the treatment. Mean ± SD of the time between the onset of MSCC and the start of radiotherapy was significantly reduced by the introduction of THERAPIST from 7.1 ± 7.9 days to 0.8 ± 0.4 days ($P < .05$). Recovery rate of nonambulant patients was significantly higher after THERAPIST (5 of 6) than before THERAPIST (2 of 8; $P < .05$). Patients who had become ambulant were treated in the outpatient clinic until the terminal stage, whereas

Table 2. Characteristics of MSCC Patients Treated With THERAPIST

Patient No.	Disease	Pretreatment Status	Time (h)*	Outcome
1	Prostate cancer	Nonambulant	6	Ambulant
2	Prostate cancer	Nonambulant	7	Ambulant
3	Prostate cancer	Nonambulant	5	Ambulant
4	Prostate cancer	Nonambulant	3	Ambulant
5	Lung cancer	Nonambulant	32	Nonambulant
6	Prostate cancer	Nonambulant	2	Ambulant
7	Lung cancer	Ambulant	7	Ambulant
8	Breast cancer	Ambulant	3	Ambulant
9	Prostate cancer	Ambulant	18	Ambulant
10	Lung cancer	Ambulant	24	Ambulant
11	Lung cancer	Ambulant	6	Ambulant
12	Bladder cancer	Ambulant	10	Ambulant

*Time from the diagnosis of MSCC to the start of radiotherapy.

nonambulant patients required hospitalization from the time of radiotherapy until death.

Cost-Benefit Analysis

The machine cost of the university hospital was \$25,000. The initial investment can be repaid within 5 years by each of the 10 district hospitals paying \$500 per year. In a branch hospital, the total machine cost is \$10,000. Annual maintenance for the network costs about \$1,000 for each hospital. Consultation for one patient required 49 minutes, at a cost of approximately \$100 for the university doctor and \$100 for the district hospital. Therefore, if one hospital uses the THERAPIST for 10 patients in a year for consultation, a patient needs to pay \$500/10 + \$10,000/10 patients/5 years + \$1,000/10 patients + \$100 + \$100 = \$550.

If a patient with MSCC is treated within the appropriate time period and recovers or is prevented from reaching paraplegia, the cost for hospitalization can be reduced. In our country, 3 months' hospitalization for a patient with paraplegia costs approximately \$10,000. Visiting nurse management for 3 months costs approximately \$3,500. For an ambulant patient, these costs are not required. The total population covered by the 10 district hospitals was roughly 5,000,000, and the incidence of MSCC was estimated to be 150 patients per year. Given that the recovery rate of nonambulant patients would likely improve from 25% (1 of 5) to 83% (5 of 6) by the introduction of THERAPIST, 87 patients per year (150 × [83 − 25]/100) could avoid 3 months' hospitalization or visiting nurse management. Total benefit of the community was estimated to be \$304,500 to \$870,000 per year.

DISCUSSION

Clinical data of treatment and efficiency improvements often is anecdotal in telemedicine studies. Recently, a randomized, controlled trial showed that telemedicine was comparable with conventional approach in the emergency department.[9] Regarding oncology, Campbell et al[11] have shown that increasing distance from a cancer center was associated with less chance of proper diagnosis and poorer survival after diagnosis. The long time between the onset of MSCC and the start of radiotherapy before the introduction of THERAPIST in this study was consistent with their findings. Although our study is not a randomized trial, the historical comparison strongly suggests that THERAPIST was effective in giving appropriate emergency radiotherapy for patients with MSCC. Leviov et al[8] reported in his review that the radiotherapeutic success rates for an MSCC were at 80% for ambulatory patients and 30% for nonambulant patients even in the best-equipped medical environment. Although the patient sampling is small, our results after the introduction of the THERAPIST were 100% (6 of 6) for ambulant and 83% (5 of 6) for nonambulant patients, which surpass the global standard of the care. Time study showed that image transfer was sufficiently rapid to be used in emergency radiotherapy. The system also was suggested to be economically beneficial for payers, providers, and patients.[10] These findings indicate that telemedicine can play a crucial role in improving treatment quality and financial expense.

The annual number of MSCC patients requiring emergency radiotherapy increased from 4 to 12 after the introduction of the THERAPIST. This finding implies that telemedicine was useful in increasing the chance of treatment for patients with MSCC at the district hospital.[11] Another advantage of telemedicine is the easy access to consultation it provides. Physicians were able to consult with the university hospital more freely after the introduction of the THERAPIST. Although the consultation time required for a doctor in the university hospital was acceptable in this study, increase in demand for consultation could create a bottleneck in consultation via telecommunication. Currently, careful selection of patients who would receive the greatest benefit from telemedicine is important to prevent collapse of the consultation system. In our community, patients who would decidedly benefit from emergency radiotherapy are now regarded as good candidates for remote consultation. Each community must have a tailored program to achieve international standard radiotherapy.[12,13] These results suggested that telecommunication such as THERAPIST could improve treatment outcome and raise the standard of treatment in district hospitals.

Clearly, face-to-face communication is most important to create a good relationship between a patient and a doctor. We do not consider that telecommunication via a TV camera is generally sufficient to create this sort of relationship. However, the patients with MSCC accepted that rapid and appropriate decisions and emergency radiotherapy with THERAPIST would be the best solution in their cases. Moreover, several pilot studies have suggested that rural patients would be satisfied with seeing their physicians in another hospital via telecommunication.[14,15] A telecommunication-helped radiation oncologist in a district hospital may well be regarded as more reliable than an equally experienced or simply degree-qualified radiation oncologist in the near future.

The telecommunication-helped radiotherapy and information system was found to be useful in emergency radiotherapy for MSCC in district hospitals where consultation with experienced radiation oncologists in a university hospital was required.

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