SUMMARY

Precise identification and preservation of the pyramidal tract during surgery for parenchymal brain tumors is of crucial importance for avoidance of postoperative deterioration of the motor function. Technique of intraoperative diffusion-weighted imaging (iDWI) using intraoperative MR scanner of low magnetic field strength (0.3 Tesla) has been developed. Its clinical usefulness and efficacy were evaluated in 10 surgically treated patients with gliomas (5 men and 5 women; mean age of 41.2 ± 13.9 years). iDWI permitted visualization of the pyramidal tract on the non-affected side in all 10 cases, and on the affected side in 8 cases. Motion artifacts were observed in four patients, but were not an obstacle for identification of the pyramidal tract. Good correspondence of the anatomical landmarks localization on iDWI and T_1-weighted imaging was found. All participating neurosurgeons agreed, that in the majority of cases iDWI was very useful for localization of the pyramidal tract and for clarification of its spatial relationships with the tumor. In conclusion, image quality and accuracy of the iDWI obtained with MR scanner of low magnetic field strength (0.3 Tesla) is sufficient for possible incorporation into intraoperative neuronavigation system. Using of iDWI in addition to structural iMRI and subcortical functional mapping with electrical stimulation can potentially result in reduction of the postoperative morbidity after aggressive surgical removal of lesions located in the vicinity to the motor white matter tracts.

KEY WORDS

intraoperative MRI

diffusion-weighted imaging

intraoperative neuronavigation

pyramidal tract

TEXT

Introduction

Precise identification and preservation of the pyramidal tract during surgery for parenchymal brain tumors is of crucial importance for avoidance of postoperative deterioration of the motor function. Intraoperative subcortical brain mapping with electrical stimulation [1,2], as well as neuronavigation, based on preoperative diffusion-weighted imaging (DWI) or diffusion tensor imaging (DTI) [3-10], are usually used for this purpose, but both of these techniques has a recognizable pitfalls. The first one can provide only functional information and does not permit precise estimation of the exact course of the pyramidal tract, whereas the second is susceptible to mislocalization errors, particularly caused by brain shift [11,12]. Technique of intraoperative DWI (iDWI) using intraoperative MR scanner of low magnetic field strength (0.3 Tesla), has been developed recently in Tokyo Women's Medical University [13,14]. After validation of the scanning protocol during pre-clinical investigation on volunteers [15], the clinical part of the study was initiated with an objective to evaluate the usefulness and efficacy of iDWI during surgical management of gliomas.

Methods and Materials

Main principles of surgery for gliomas with use of iMRI of low (0.3 Tesla) magnetic field strength (AIRIS II, Hitachi Medical, Tokyo, Japan) adopted in the Tokyo Women's Medical University had been presented previously [16]. Shortly, after induction of the general anesthesia, the patient head was firmly fixed with titanium pins in the modified Sugita head-holder (Fig.1), representing lower arch of the headholder-coil (Mizuho Ltd., Tokyo, Japan). The head-holder was connected to the operating table with supporting arm incorporating 3 joints and 2 rotational axes, which provided easy adjustment of the head position according to the surgical needs. For preservation of sterile conditions in the surgical field during the procedure the patient head was covered with transparent drapes, whereas electrical connectors of the headholder-coil were protected with special caps to prevent contamination with fluids and dust. Before start of iMRI several fiducial markers were fixed to the skull on the periphery of the surgical field, and additional one was inserted into the surgical wound and located in the vicinity to the target. The protective caps were removed from the electrical connectors and both semicircular arches of the headholder-coil were connected. Wide transparent sterile drape was used to cover the whole body of the patient, his or her head, and surgical wound, and the operating table was moved into gap of the intraoperative MR scanner. During routine surgery iMRI was usually performed at least 2 times: after craniotomy and completeness of the approach to the tumor and after resection of the neoplasm. If additional resection of glioma was required iMRI investigation was repeated.

Clinical data

Evaluation of the clinical usefulness of iDWI was performed in 10 surgically treated patients with gliomas located in the vicinity to the pyramidal tract. There were 5 men and 5 women with a mean age of 41.2 ± 13.9 years (range: 26 – 68 years). Initially diagnosed tumors were met in 8 patients, whereas recurrent in 2. According to histopathological examination there were two astrocytomas WHO grade II, two anaplastic astrocytomas WHO grade III, two anaplastic oligodendrogliomas WHO grade III, and four glioblastomas WHO grade IV. Nine patients were operated on in supine, and one in prone position. The study was approved by responsible authorities of the Tokyo Women's Medical University and informed consent was obtained from each patient and his/her nearest family member.

Evaluation of the pyramidal tract contrasting

According to objectives of the present study in all cases in addition to usually used axial T_2-weighted and axial T_1-weighted imaging with or without contrast enhancement, which took approximately 10 minutes, additional shimming, DWI, and coronal T_1-weighted imaging were done, which required additional 15 – 20 minutes. T_1-weighted images and T_2-weighted images were obtained using, respectively, 3D gradient echo (RSSG, RF-spoiled steady state acquisition rewound gradient echo with TR 27 ms and TE 10ms), and 3D fast spin echo with driven equilibrium pulse (TR 1000 ms, TE 140 ms), with scan matrix size 256 × 160, 100 slices, 1.5 mm slice interval for both imagings. DWI was acquired according to the protocol described previously [15] using application of the motion probing gradient (MPG) pulse in anteroposterior direction taken into account the actual position of the patient head. iDWI was performed both before and after tumor resection in 9 cases, and only before tumor removal in one. Two evaluations (one before and one after tumor resection) were excluded from the further analysis due to violation of the unified protocol for iDWI. Seventeen residual investigations, incorporating 306 slices, were evaluated, and pyramidal tract contrast ratios were measured as described previously [15], and compared between affected and non-affected sides. Additionally, the contrast ratio of pyramidal tracts was compared between patients and previously investigated healthy volunteers [15].

Evaluation of iDWI accuracy

For evaluation of distortion artifacts on iDWI the distances between image centerline (near the midline) to the lateral cerebral ventricle wall, indicating the position of the pyramidal tract, and to the cortical surface were measured, correspondingly in 11 affected and 15 non-affected sides (with the exception of cases in which lateral ventricle wall could not be identified due to mass effect), and 17 affected and 17 non-affected sides. The same distances were measured on T_1-weighted images. The differences of these measurements were calculated and named as distortion indices corresponding to displacement of the lateral ventricle and displacement of the cortical surface, which were compared between each other.

Evaluation of the clinical usefulness of iDWI

For evaluation of the clinical utility of iDWI during surgery for gliomas, 5 neurosurgeons with an average surgical experience of 12.6 ± 4.7 years (range: 8 – 20 years) were asked to complete a specially designed questionnaire and to answer whether iDWI-based determination of the pyramidal tract was useful and for which purpose, and what problems of this technique are seemingly interfere with the clinical needs.

Statistics

Two-tailed t-test was used for statistical analysis. The level of significance was determined at $P < 0.05$.

Results

Using of the modified Sugita head-holder (lower arch of the headholder-coil) during microneurosurgical procedure provided firm and stable fixation of the patient head and was not accompanied by any troubles in any case. In all 10 patients intraoperative T_1-weighted and T_2-weighted images provided sufficient visualization of the brain tumor, as well as its remnants after incomplete resection (Fig.2). The total iMRI investigation time in cases which included iDWI, calculated from attachment of the upper semicircular arch of the headholder-coil to its removal for continuation of the surgical procedure, constituted approximately 40 minutes.

Evaluation of the pyramidal tract contrasting

iDWI permitted visualization of the pyramidal tract on the non-affected side in all 10 cases, and on the affected side in 8 cases (Fig.3). In 2 patients with malignant gliomas clear visualization of the pyramidal tract on the affected side was not possible (Fig.4). The tract contrast ratios varied from 84.5% to 17.7%, and constituted in average 43.7±16.4%. The differences of the tract contrast ratio between non-affected and affected side, as well as between patients and previously investigated healthy volunteers [15] were not statistically significant. Motion artifacts were observed in four patients with pulse rate over 70 per minute, but were not an obstacle for identification of the pyramidal tract position by neurosurgeons.

Evaluation of iDWI accuracy

The average displacement at the lateral ventricle on the affected side constituted 1.0±0.7 mm. The differences of the distortion indices between lateral ventricle wall and cortical surface were not statistically significant on the affected side, but were significant on non-affected one (Table 1). Good correspondence of the anatomical landmarks localization on iDWI and T_1-weighted imaging was found (Fig.5).

Evaluation of the clinical usefulness of iDWI

All participating neurosurgeons agreed, that iDWI was very useful for localization of the pyramidal tract and for clarification of its spatial relationships with glial tumors and normal cerebral tissue in the majority of patients (Table 2). Among problems, which can interfere with the clinical needs, increase of required iMRI examination time, and poor tract visualization in some cases of malignant gliomas, were marked.

Discussion

Simultaneous use of iDWI and structural iMRI during surgery for parenchymal brain tumors seems to be extremely useful for determination of both white matter tracts position and lesion location. However, additional incorporation of iDWI into intraoperative neuronavigation system requires high level of image quality and positional accuracy. We estimated that the latter should be within 5 mm, which corresponds to the conducting depth of the electrical stimulation during subcortical brain mapping. It was previously shown, that mean error of the intraoperative neuronavigation system using T_1-weighted images obtained with MR scanner of low magnetic field strength (0.3 Tesla) in the "intelligent operating theater" of the Tokyo Women's Medical University is as low as 0.90 ± 0.35 mm [17]. In the present study the misalignments between DWI and T_1-weighted images on the affected side were 1.0 ± 0.7 mm for the lateral ventricle wall and 1.2 ± 1.1 mm for the cortical surface, which corresponds to the estimated positional accuracy of approximately 2.1 mm, and, in our opinion, fulfils clinical needs.

Motion artifacts were observed in four patients with pulse rate over 70 per minute. Jiang et al. [18] reported, that effect of pulsation can be minimized by avoiding the period of 100 to 250 msec after systole for data acquisition. In our pre-clinical study [15] motion artifacts in multi-shot DWI-echo-planar imaging were successfully suppressed by setting time delay from the systole on more than 300 msec. It should be marked, that under general anesthesia, pulse rate is usually well controlled. Nevertheless, in no one case motion artifacts interfered with identification of the pyramidal tract position by neurosurgeons.

Diffusion anisotropy of the white matter tracts may be reduced by presence of the lesion or perilesional edema [19]. In some cases of the present study location of malignant glioma in the close proximity to the pyramidal tract resulted in its poor visualization on iDWI. While pre-operative DWI can define whether pyramidal tract can be visualized or not, it may not correspond completely to results of intraoperative imaging. Using of visual comparison of images obtained with different directions of MPG pulses, Krings et al. [6] were able to differentiate edema from the large descending fiber tracts in all 10 patients with various brain lesions.

All neurosurgeons participating in the present study found iDWI very useful for determination of the pyramidal tract positioning and its spatial relationships with the lesion and surgical instruments. It may become even more convenient in the future, due to development of the special sound alarm, which will be automatically activated when surgical manipulations would come into close proximity to the pyramidal tract [20]. It should be marked, however, that protocol used for acquisition of iDWI provided limited image resolution of 2.5 × 2.7 mm in both mediolateral and craniocaudal directions, whereas slice thickness of 8 mm resulted in partial volume effect. These factors can reduce differentiation of the fine structures within the pyramidal tract, and necessitate use of subcortical brain mapping with electrical stimulation in addition to iDWI [9,21].

Prolongation of time required for examination, which constituted approximately 40 minutes, was marked as a problem, which can interfere with the clinical usefulness of the technique. In fact, investigation time can be shorten if coronal T_1-weighted would be omitted and shimming would be minimized to the region-of-interest. From another side, similarly to any other type of iMRI potential decrease of postoperative morbidity and improvement of quality of life can be considered as a reasonable prize for prolongation of the total length of surgery.

In conclusion, the results of the present clinical study show, that iDWI using MR scanner of low magnetic field strength (0.3 Tesla) in the majority of patients permits clear visualization of the pyramidal tract and identification of its spatial relationships with the lesion and surgical instruments. Image quality and accuracy were sufficient for possible incorporation of iDWI into intraoperative neuronavigation system. Using of iDWI in addition to structural iMRI and subcortical functional mapping with electrical stimulation can potentially result in reduction of the postoperative morbidity after aggressive surgical removal of lesions located in the vicinity to the motor white matter tracts.

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Table 1. Comparison of distortion indices calculated using intraoperative DWI and T_1-weighted images obtained with MR scanner of low magnetic field strength (0.3 Tesla).

	Affected side	Non-affected side
Displacement of the lateral ventricle (mm)	1.0 ± 0.7 (n = 11)	0.6 ± 0.5 (n = 15)
Displacement of the cortical surface (mm)	1.2 ± 1.1 (n = 17)	0.9 ± 0.5 (n = 17)
P-value	NS	< 0.05

Data presented as mean ± standard deviation; NS: non-significant; n: number of cases

Table 2 Results of the evaluation of usefulness of intraoperative DWI for visualization of the pyramidal tract

Standard questions to five practicing neurosurgeons	Number of answers
Whether visualization of the pyramidal tract with iDWI was:	
very useful	5 (100%)
useful	0
not useful	0
Whether visualization of the pyramidal tract with iDWI was useful for:	
determination of its position	5 (100%)
determination of its shift	2 (40%)
determination of its spatial interrelationships with the lesion	5 (100%)
for other purposes	0
What problems with iDWI were encountered:	
long imaging time	5 (100%)
poor contrasting of the pyramidal tract	1 (20%)
poor image resolution	0
low signal-to-noise ratio	0
presence of image artifacts	0
others	3 (60%)

iDWI: intraoperative diffusion-weighted imaging

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LEGENDS FOR FIGURES

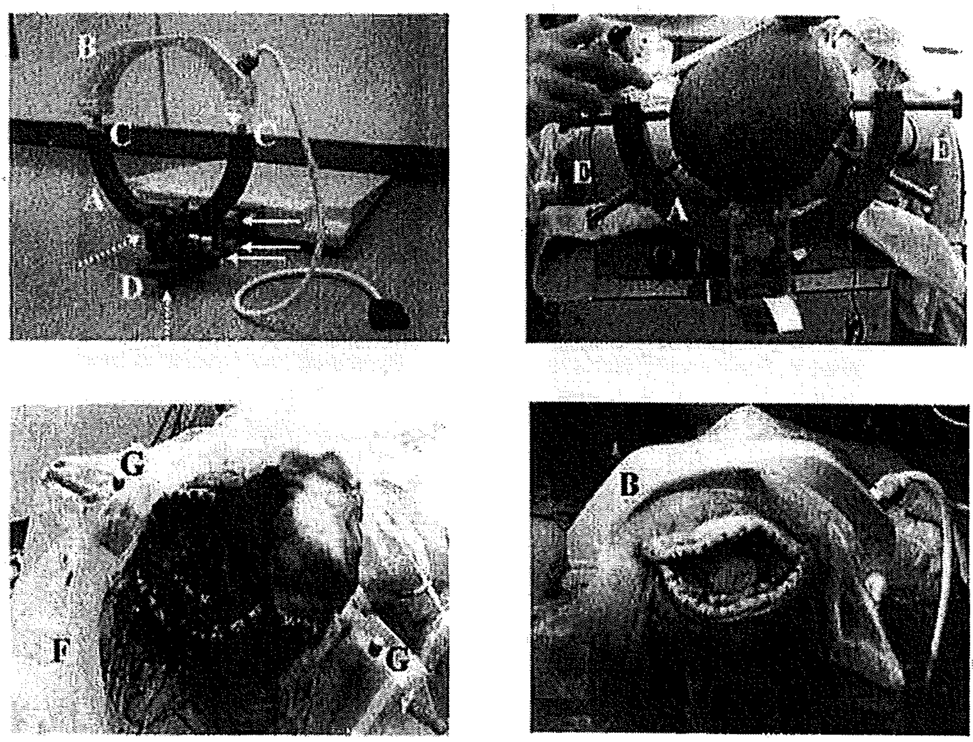

Figure 1

Radiofrequency receiver coil integrated with modified Sugita head holder for intraoperative MRI (Headholder-coil; Mizuho Ltd., Tokyo, Japan): general view of the device (*upper left*), fixation of the patient head within modified Sugita head holder before craniotomy (*upper right*) and during the surgical procedure (*lower left*), connection of both semicircular arches before intraoperative imaging, which provides solenoid coil structure (*lower right*). Marked: modified Sugita head holder with built-in cupper wire (A), removable upper semicircular arch (B), electrical connectors (C), supporting arm for fixation to the operating table (D) with its 3 joints (solid arrows) and 2 rotational axes (dashed arrows) for adjustment of the patient head position, titanium fixation pins (E), sterile surgical drapes (F), sterile protective caps, covering the electrical connectors during surgery (G).

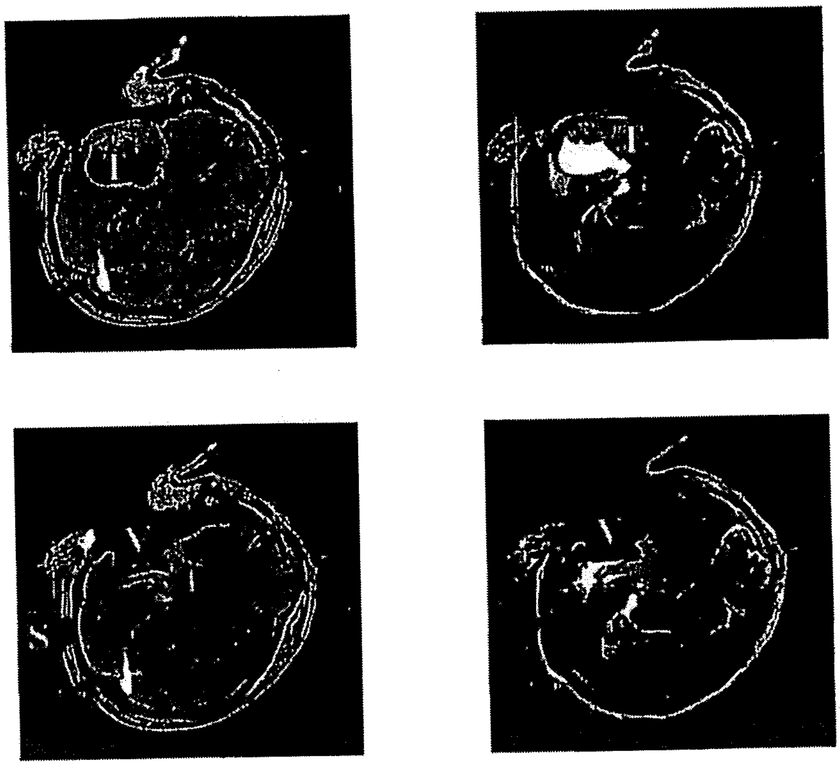

Figure 2

Axial intraoperative contrast-enhanced T_1-weighted (*left column*) and T_2-weighted (*right column*) images before (*upper row*) and after (*lower row*) removal of the temporal lobe glioblastoma, which were acquired with intraoperative MR scanner of low magnetic field strength (0.3 Tesla) using originally designed radiofrequency receiver coil integrated with modified Sugita head holder (headholder-coil). Note good image resolution, which permits their use for intraoperative neuronavigation, and minimal area of signal loss (S) at the point of contact of the titanium fixation pin with the scalp and cranium. Marked: tumor (T), resection cavity (V).

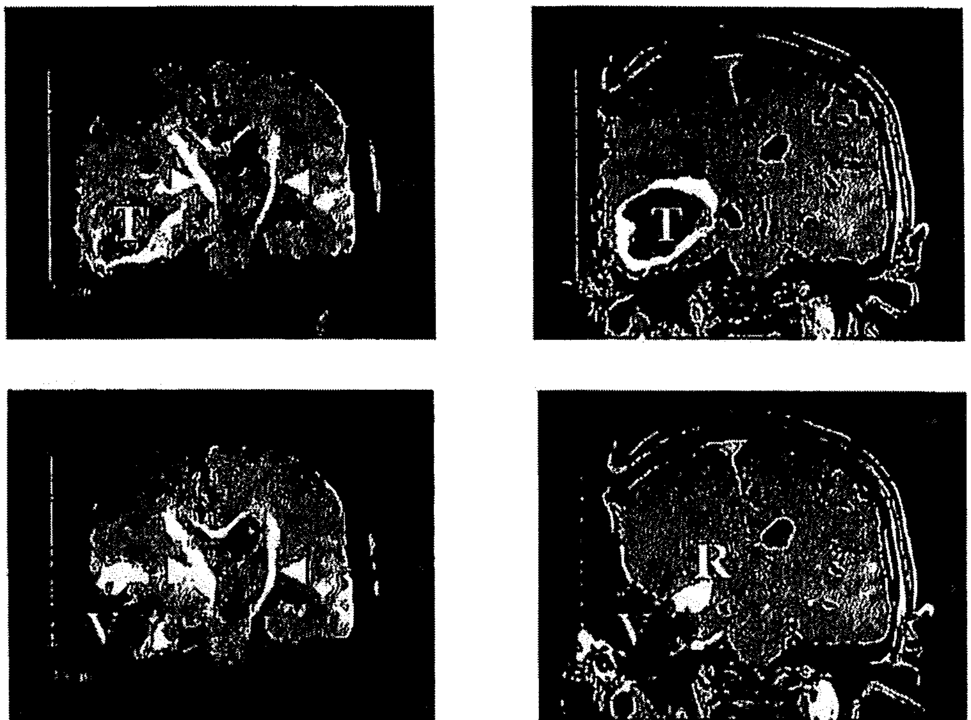

Figure 3

Coronal intraoperative diffusion-weighted (*left column*) and contrast-enhanced T_1-weighted (*right column*) images before (*upper row*) and after (*lower row*) removal of the temporal lobe glioblastoma, which were acquired with intraoperative MR scanner of low magnetic field strength (0.3 Tesla) using originally designed radiofrequency receiver coil integrated with modified Sugita head holder (headholder-coil). Note good image resolution, which permits their use for intraoperative neuronavigation, and clear visualization of the pyramidal tract with diffusion-weighted imaging. Marked: tumor (T), resection cavity (V), residual part of the neoplasm after its incomplete resection (R).

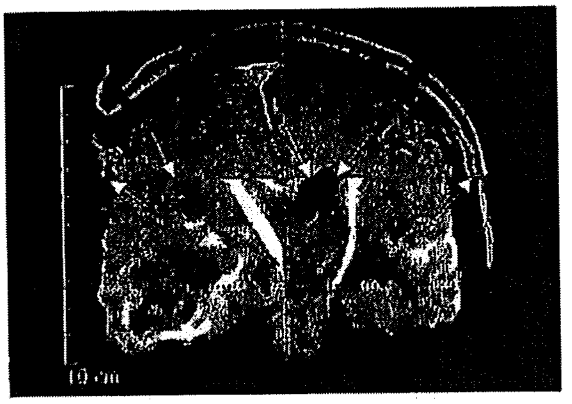

Figure 4

An intraoperative diffusion-weighted image with insufficient visualization of the pyramidal tract on the affected side compared to the non-affected side (*arrowheads*). Marked: peritumoral edema (E).

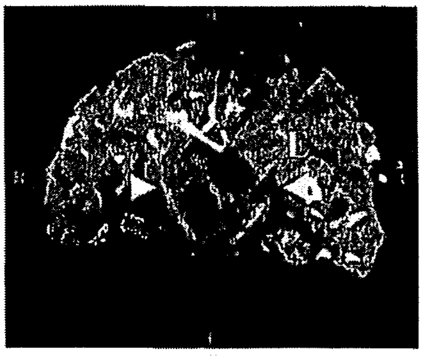

Figure 5

Evaluation of accuracy of the intraoperative DWI (*lower part*) superimposed on corresponding T_1-weighted image (*upper part*). Note that, with exception of cortical surface, there was good correspondence of the anatomical landmarks localization (*arrows*).

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5TH JUCTS AND THE 5TH S. TAKAHASHI MEMORIAL INTERNATIONAL JOINT SYMPOSIUM

SURVEY OF STEREOTACTIC BODY RADIATION THERAPY IN JAPAN BY THE JAPAN 3-D CONFORMAL EXTERNAL BEAM RADIOTHERAPY GROUP

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Purpose: To recognize the current status of stereotactic body radiotherapy (SBRT) in Japan, using a nationwide survey conducted by the Japan 3-D Conformal External Beam Radiotherapy Group.
Methods and Materials: The questionnaire was sent by mail to 117 institutions. Ninety-four institutions (80%) responded by the end of November 2005. Fifty-three institutions indicated that they have already started SBRT, and 38 institutions had been reimbursed by insurance.
Results: A total of 1111 patients with histologically confirmed lung cancer were treated. Among these patients, 637 had T1N0M0 and 272 had T2N0M0 lung cancer. Metastatic lung cancer was found in 702 and histologically unconfirmed lung tumor in 291 patients. Primary liver cancer was found in 207 and metastatic liver cancer in 76 patients. The most frequent schedule used for primary lung cancer was 48Gy in 4 fractions at 22 institutions (52%), followed by 50Gy in 5 fractions at 11 institutions (26%) and 60Gy in 8 fractions at 4 institutions (10%). The tendency was the same for metastatic lung cancer. The average number of personnel involved in SBRT was 1.8 radiation oncologists, including 1.1 certified radiation oncologists, 2.8 technologists, 0.7 nurses, and 0.6 certified quality assurance personnel and 0.3 physicists. The most frequent amount of time for treatment planning was 61–120min, for quality assurance was 50–60min, and for treatment was 30min. There were 14 (0.6% of all cases) reported Grade 5 complications: 11 cases of radiation pneumonitis, 2 cases of hemoptysis, and 1 case of radiation esophagitis.
Conclusion: The current status of SBRT in Japan was surveyed. © 2009 Elsevier Inc.

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The following institutes in Japan participated in this survey: National Defense Medical College, Yamanashi University, Tohoku University, Keio University, Osaka Rosai Hospital, Hokkaido University, Yamagata Saiseikan Hospital, Hiroshima University, Tokyo Metropolitan Hiroo Hospital, Oita National Hospital, Asahikawa Municipal Hospital, Kitazato University, Tokyo University, Nara Medical College, Kagoshima Satunan Hospital, Kobe IBRI Hospital, Saitama Medical College, NTT East Sapporo Hospital, Gifu University, Hakodate Municipal Hospital, Ibaraki Prefectural Central Hospital, Obihiro Kosei Hospital, Mie University, Chiba Cancer Center, Showa University, Kyushu University, Hyogo Medical Center for Adults, Nagasaki Prefectural Shimabara Hospital, Sapporo Municipal Hospital, Fukui Red Cross Hospital, Kameda General Hospital, Yamaguchi University, Daiyukai General Hospital, Musashino Red Cross Hospital, Hokkaido Cancer Center, Sapporo Medical College, Nihon University, Handa Municipal Hospital, Tenri Hospital, Saitama Cancer Center, Tokyo Medical College Hachioji Center, Aichi Cancer Center, Hiroshima Red Cross Hospital, Kobe University, Kashiwabara General Hospital, Hitachi General Hospital, Hirosaki University, Iwate Tanzawa Hospital, Sendai Kosei Hospital, Furukawa Municipal Hospital, Takeda General Hospital, Tokyo Metropolitan Komagome Hospital, Nagaoka Red Cross Hospital, Fukui University, Hiroshima Prefectural Hospital, Tokushima University, Kagawa University, Kumamoto University, West Kobe Medical Center, Jyuntendo University Hospital, Osaka Medical College, Asahikawa Kohsei Hospital, Gunma University, Japan Defense Structure Central Hospital, St. Luke's International Hospital, Maebashi Red Cross Hospital, Sagamihara Kyodo Hospital, Toyama Municipal Hospital, Shizuoka Saiseikai Hospital, Shiga University, Rinku Central Medical Center, Kurume University, Niigata Cancer Center, Aichi Medical College, Asanokawa General Hospital, Ehime University, Osaka University, Osaka City University, Osaka Red Cross Hospital, Osaka Medical Center for Cancer, Okayama University, Nagoya Second Red Cross Hospital, Kanazawa University, Kawasaki Medical College, Nagoya City University, Nagoya University, The Cancer Institute Hospital, Gifu Prefectural Hospital, Yokohama Municipal Hospital, Kyushu Cardiovascular Center, Kinki University, Konan St. Hill Hospital, National Cancer Center Hospital, National Cancer Center Hospital East, National Kure Hospital, Saga University, Shikoku Cancer Center, Shizuoka Cancer Center, Yokohama Rosai Hospital, Shizuoka General Hospital, Jichi University, JA Hiroshima General Hospital, Yamagata University, St. Marianna University, Seirei Hamamatsu General Hospital, Teikyo University, Tokai University, Tokyo Medical University, Tokyo Women's Medical University, Toyohashi Municipal Hospital, Nagasaki University, Nagoya National Hospital, and Kyoto University.

Conflict of interest: none.

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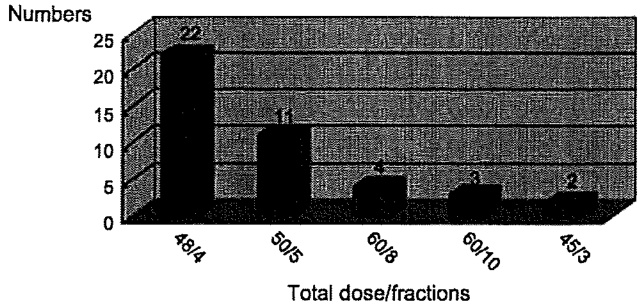

Fig. 1. Fractionation schedules of stereotactic body radiotherapy used in primary T1N0M0 lung cancer. The most common schedule was 48 Gy in 4 fractions.

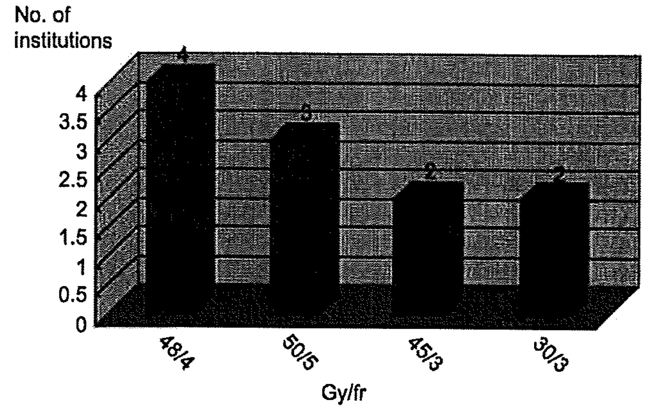

Fig. 3. Fractionation schedules of stereotactic body radiotherapy used in primary liver cancer. The most common schedule was 48 Gy in 4 fractions.

SBRT, Survey, Stereotactic radiotherapy, Lung cancer, Liver cancer.

INTRODUCTION

Stereotactic body radiotherapy (SBRT) is a new technique to treat early lung or liver cancer. This technique uses a hypofractionation schedule and was introduced in the late 1990s (1–5). Recently, many articles have been published from Japan, the European Union, and the United States describing promising clinical results, especially for early-stage lung cancer (6–31). However, a few complications, including death, have also been reported. Because reimbursement for this treatment was approved by the Japanese governmental health insurance in 2004, a rapid increase has been seen in the number of institutions providing SBRT. Therefore, to appraise the present status of SBRT in Japan, a nationwide survey was conducted by the Japan 3-D Conformal External Beam Radiotherapy Group.

METHODS AND MATERIALS

To review the current status of SBRT in Japan, this study was conducted to evaluate the number of institutions, number of patients, quality assurance (QA), technique, and complications of SBRT.

This questionnaire was mailed to 117 institutions. Ninety-four institutions (80%) responded by the end of November 2005. Fifty-three institutions indicated having already started SBRT, and 38 institutions had already received reimbursement from the government.

RESULTS

A total of 1111 patients with histologically confirmed lung cancer were treated. Stagewise among these patients, 637 had T1N0M0, 272 had T2N0M0, and 202 had T3–4N0M0 lung cancer. Metastatic lung cancer was found in 702 patients and histologically unconfirmed but radiologically diagnosed lung tumor in 291. Primary liver cancer was found in 207 patients and metastatic liver cancer in 76.

The most frequent schedules used for primary lung cancer were 48 Gy in 4 fractions at 22 institutions (52%), followed by 50 Gy in 5 fractions at 11 institutions (26%) and 60 Gy in 8 fractions at 4 institutions (10%), as shown in Fig. 1. The schedule tended to be the same for metastatic lung cancer, as shown in Fig. 2.

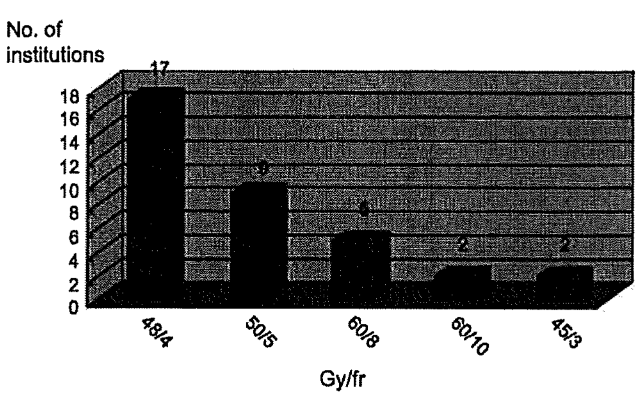

Fig. 2. Fractionation schedules of stereotactic body radiotherapy used in primary T2N0M0 lung cancer. The most common schedule was 48 Gy in 4 fractions.

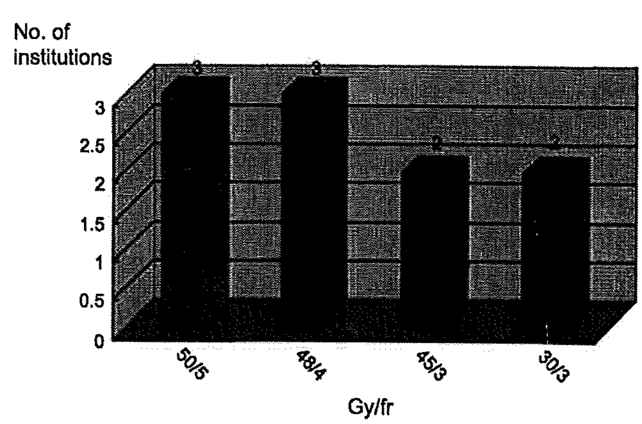

Fig. 4. Fractionation schedules of stereotactic body radiotherapy used in secondary liver cancer. The most common schedules were 50 Gy in 5 fractions and 48 Gy in 4 fractions.