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# A national survey of medical staffs' required capability and workload for accelerator-based boron neutron capture therapy

Satoshi Nakamura[1,2,3], Hiroki Tanaka[4], Takahiro Kato[5,6], Kazuhiko Akita[7], Mihiro Takemori[2,9,10], Yusaku Kasai[3,11], Tairo Kashihara[2,9], Yoshihiro Takai[12], Keiji Nihei[7,8], Hiroshi Onishi[13] and Hiroshi Igaki[2,9,*]

[1]Division of Radiation Safety and Quality Assurance, National Cancer Center Hospital, 5-1-1 Tsukiji, Chuo-ku, Tokyo 104-0045, Japan
[2]Division of Boron Neutron Capture Therapy, National Cancer Center Exploratory Oncology Research & Clinical Trial Center, 5-1-1 Tsukiji, Chuo-ku, Tokyo 104-0045, Japan
[3]Medical Physics Laboratory, Division of Health Science, Graduate School of Medicine, Osaka University, 1-7 Yamadaoka, Suita City, Osaka 565-0871, Japan
[4]Particle Radiation Oncology Research Center, Institute for Integrated Radiation and Nuclear Science, Kyoto University, 2-1010 Asashiro-Nishi, Kumatori-cho, Sennan-gun, Osaka 590-0494, Japan
[5]Department of Radiological Sciences, School of Health Sciences, Fukushima Medical University, 10-6 Sakae-machi, Fukushima City, Fukushima 960-8516, Japan
[6]Department of Radiation Physics and Technology, Southern Tohoku BNCT Research Center 7-10 Yatsuyamada, Koriyama, Fukushima 963-8052, Japan
[7]Kansai BNCT Medical Center, Osaka Medical and Pharmaceutical University, 2-7 Daigakumachi, Takatsuki-shi, Osaka 569-8686, Japan
[8]Department of Radiation Oncology, Osaka Medical and Pharmaceutical University, 2-7 Daigakumachi, Takatsuki-shi, Osaka 569-8686, Japan
[9]Department of Radiation Oncology, National Cancer Center Hospital 5-1-1 Tsukiji, Chuo-ku, Tokyo 104-0045, Japan
[10]Department of Radiology and Radiation Oncology, Edogawa Hospital, 2-24-18 Hgashikoiwa, Edogawa-ku, Tokyo 133-0052, Japan
[11]Department of Radiological Technology, National Cancer Center Hospital, 5-1-1 Tsukiji, Chuo-ku, Tokyo 104-0045, Japan
[12]Department of Radiation Oncology, Southern Tohoku BNCT Research Center, 7-10 Yatsuyamada, Koriyama, Fukushima 963-8052, Japan
[13]Department of Radiology, University of Yamanashi, 1110 Shimokato, Chuo-shi, Yamanashi 409-3898, Japan
*Corresponding author. Department of Radiation Oncology, National Cancer Center Hospital, 51-1 Tsukiji, Chuo-ku, Tokyo 104-0045, Japan. Tel: +81-3-35-42-25-11; Fax: +81-3-35-45-356-7; Email: hirigaki@ncc.go.jp

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## ABSTRACT

This study aimed to identify the required capabilities and workload of medical staff in accelerator-based boron neutron capture therapy (BNCT). From August to September 2022, a questionnaire related to the capabilities and workload in the accelerator-based BNCT was administered to 12 physicians, 7 medical physicists and 7 radiological technologists engaged in BNCT and 6 other medical physicists who were not engaged in BNCT to compare the results acquired by those engaged in BNCT. Only 6–21% of patients referred for BNCT received it. Furthermore, 30–75% of patients who received BNCT were treated at facilities located within their local district. The median required workload per treatment was 55 h. Considering additional workloads for ineligible patients, the required workload reached ∼1.2 times longer than those for only eligible patients' treatment. With respect to capabilities, discrepancies were observed in treatment planning, quality assurance and quality control, and commissioning between medical physicists and radiological technologists. Furthermore, the specialized skills required by medical physicists are impossible to acquire from the experience of conventional radiotherapies as physicians engaged in BNCT were specialized not only in radiation oncology, but also in other fields. This study indicated the required workload and staff capabilities for conducting accelerator-based BNCT considering actual clinical conditions. The workload required for BNCT depends on the occupation. It is necessary to establish an educational program and certification system for the skills required to safely and effectively provide BNCT to patients.

**Keywords:** boron neutron capture therapy (BNCT); accelerator-based BNCT; workload; capability; specialized procedure

## INTRODUCTION

Boron neutron capture therapy (BNCT), which utilizes an accelerator-based neutron source, is a recent advancement in radiotherapy. The principle of therapeutic efficacy is based on the $^{10}B(n, \alpha)^{7}Li$ reactions. The aforementioned particles demonstrate notable linear energy transfer, and the biological effect of BNCT surpasses that of conventional radiotherapy [1]. The anticipated selective death of tumor cells can be attributed to the comparable size ranges of the particles within that of target cells, as well as the increased concentration of $^{10}B$ particles in the tumor compared to the surrounding normal tissues.

The biological effectiveness of the boron neutron capture reaction has been established via experimental investigations [1]. Clinical trials for BNCT have been conducted in research reactors, and favorable clinical outcomes have been reported in previous studies [2,3]. Nonetheless, the regulatory and safety considerations associated with the utilization of a nuclear reactor as a neutron source have restricted the extensive implementation of BNCT. Recent studies have supported the utilization of accelerator-based neutron sources for BNCT in medical facilities [4,5]. Based on the excellent results of clinical trials, accelerator-based BNCT for recurrent or locally advanced head and neck cancer has been provided as a public insurance treatment in Japan since June 2020 [4]. Furthermore, clinical trials of other malignancies have been conducted to expand the indications for its use [6–8]. Hence, further developments in BNCT are being promoted, and an increased medical demand can be expected for BNCT. Therefore, it is necessary to obtain data to establish an appropriate framework for providing BNCT to patients, considering the estimated future increase in the demand for BNCT. However, there are no reports on the required workload and capabilities for accelerator-based BNCT. Furthermore, the existing reports related to BNCT standardization were limited and insufficient to standardize the work items for BNCT. This study aimed to identify the required capability and workload of medical staff in accelerator-based BNCT to meet the increased demand. The results of this study are expected to contribute to the establishment of appropriate staffing system at medical facilities to provide accelerator-based BNCT to patients, as well as a social structure for medical coordination.

## MATERIALS AND METHODS

This study was approved by the Institutional Review Board (IRB) of National Cancer Center Hospital, Tokyo, Japan (approval number: 2021–476). A survey of clinical workloads and capabilities required for accelerator-based BNCT was conducted between July and August 2022. The survey covered facilities where accelerator-based BNCT had already been clinically implemented and been reported as of February 2022 in the world. It was because application of the IRB for this study was initiated at that time. Therefore, the three facilities located in Japan were included in this study (Insurance treatment: 2, Clinical trial: 1). Furthermore, those facilities had more than 2 years of clinical experience at the time of the survey, and it was expected that the sophisticated staffing systems were established.

### General facility information

Survey data on general information were obtained from the representative of each facility. The survey item included facility information and patient volume, including both the eligible and ineligible patient. Table 1 presents the items used in the general information. The local districts of patient residence were also surveyed at each facility and were divided into eight groups (A–H) according to the administrative districts of Japan.

### Workload survey

Survey data on workloads were obtained from the representative of each facility. The workload was calculated by multiplying the number of medical staff members by the number of working hours. Participants in the workload survey were physicians, medical physicists, registered nurses and radiological technologists. Table 2 presents the items used in the workload survey. The survey items included workload for both clinical and quality assurance (QA) procedures. The survey focused on the workloads required to treat one patient undergoing BNCT by a medical staff, because the indications for BNCT were still limited. The workload for QA was divided by the number of patients who could be accepted during the year.

**Table 1. Facility information survey items**

| |
|---|
| 1. General information |
| How many patients can you accept per week? |
| 1–1. Eligible patient treatment |
| How many of the patients actually treated reside in each of the local districts of A-H? |
| Number of patients accepted per week |
| What is the average number of days from application to first medical examination? |
| What is the average number of days from the first visit to the date of treatment? |
| 1–2. Ineligible patients |
| Number of cases who were consulted for BNCT in the last year but were determined ineligible for BNCT based solely on verbal or telephone information |
| Number of patients who were consulted for BNCT in the past year but were determined ineligible for BNCT after a detailed review of the ordered images and medical information sheets. |
| ·Among them, ineligible decisions based on the medical information sheet, etc. |
| ·Among them, ineligible decisions after hospital visiting |

**Table 2. Workload survey items**

| Work task | Main occupations | Work category (1–3)[a] |
|---|---|---|
| 1. Clinical work | | |
| Treatment appointments | MD | 1 |
| Conferences in the radiation oncology department | MD | 1 |
| Preliminary explanation of taking CT images and irradiation | RT | 1 |
| Immobilization devices selection | MP, RT | 1 |
| Additional time for customized shell fabrication | MP, RT | 1 |
| Additional time for vacuum cushion creation | MP, RT | 1 |
| Additional time for complicated treatment posture | MP, RT | 1 |
| Taking plain CT imaging with the immobilization devices | MP, RT | 1 |
| Additional time for contrast-enhanced CT | MP, RT | 1 |
| Image import | MP | 1 |
| Image fusion | MP | 1 |
| Contouring | MP | 1 |
| Treatment planning | MP | 1 |
| Calculation time for dose distribution | (MP)[b] | 1 |
| Consideration of activation for implant metal | MP | 1 |
| Plan approval | MD | 1 |
| Plan check | MP | 1 |
| Irradiation preparation | MP, RT, RN | 2 |
| Irradiation | MP, RT, RN | 2 |
| Treatment data management | MD, MP | 3 |
| 2. QA/QC work | | |
| 2–1. Patient-specific work | | |
| Neutron measurement using activation foil method | MP | 3 |
| Gamma-ray measurement using TLD or glass dosimeter | MP | 3 |
| Confirmation of dose verification and report preparation | MP | 3 |
| 2–2. Treatment machine[c] | | |
| Daily QA of treatment machine | MP, RT | 3 |
| Weekly QA of treatment machine | MP, RT | 3 |
| QA for replacement of consumable parts of treatment machine | MP, RT | 3 |
| Other QA of treatment machine | MP, RT | 3 |
| 2–3. Planning CT equipment | | |
| Daily QA of CT equipment | MP, RT | 3 |
| Weekly QA of CT equipment | MP, RT | 3 |
| Other QA of CT equipment | MP, RT | 3 |
| 3. Radiation management work | | |
| Control of residual radioactivity | MP | 3 |
| Quantification of radioactivity of instruments/irradiated materials | MP | 3 |
| Radiation contamination test | MP | 3 |
| 4. General work | | |
| Development of BNCT (including patient recruitment) | MD, MP | 3 |
| Other BNCT implementation-related work (such as item and treatment schedule management, and follow-up data acquisition after BNCT, etc.) | MD, MP | 3 |
| Others (radiation safety and human resource and department managements) | MP, RT | 3 |

MD = medical doctor, MP = medical physicist, RN = registered nurse, RT = radiological technologist
[a]Work was categorized as follows: 1. Treatment preparations, 2. Treatment day procedures, 3. QA procedures and the others. [b]Calculation time was excluded from the workload of medical physicist. [c]Collected only at medical institutions that provide insurance treatment.

**Table 3. Capability survey for BNCT work items in medical physicist and radiological technologist**

| | |
|---|---|
| 1. General information | |
| Age | |
| Academic degree | |
| Office organization | |
| Years of experience in radiotherapy | |
| 2. Clinical work capability | |
| Reply, 0: Non-implementable, 1: Implementable, 2: Implementable and teachable | Category[a] |
| Taking planning CT (including creation of immobilization devices) | 1 |
| Contouring of Organ-at-risks on treatment planning | 2 |
| Create treatment planning | 2 |
| Treatment planning check in terms of the medical physics | 2 |
| Confirmation of induced radionuclide | 2 |
| Treatment planning approval in terms of the medical physics | 2 |
| Data input to BNCT device and peripheral device | 3 |
| Treatment planning check in terms of the feasibility and the medical safety | 3 |
| Management of treatment schedule | 3 |
| Management for necessary items (including consumables, required for inductively coupled plasma device, etc.) | 3 |
| Confirmation of boron concentration validity in a patient | 3 |
| Determination of final monitor unit reflecting the actual boron concentration in a patient | 3 |
| Patient setup and image guidance at the treatment | 4 |
| Determination of the final position at the treatment | 4 |
| 3. QA and QC work capability | |
| Neutron measurement for QA and QC procedures | 5 |
| Contaminated gamma-ray measurement for QA and QC procedures | 5 |
| QA of BNCT device | 5 |
| Proposing the countermeasure based on the results of QA/QC | 5 |
| 4. Management work capability | |
| Management of the residual radioactivity | 6 |
| Quantification of radioactivity of instruments/irradiated materials | 6 |
| Radiation contamination test | 6 |
| Implementation of new or updated BNCT device | 7 |
| Implementation of new or updated treatment planning system for BNCT | 7 |
| Implementation of new or updated peripheral devices | 7 |
| Risk management of BNCT | 8 |

[a]Work was categorized as follows: 1. Simulation for treatment, 2. Treatment planning, 3. Treatment preparation, 4. Treatment, 5. QA and QC, 6. Radiation control, 7. Commissioning, 8. Risk management.

## Staff capability survey

The staff capabilities were collected via a survey with the medical staff working at the three facilities using Google Forms. The survey participants included physicians, medical physicists and radiological technologists. Tables 3 and 4 list the items in the capability survey for medical physicists and radiological technologists, and physicians, respectively. The survey items were common between the medical physicist and the radiological technologist but differed from those of the physician, because the medical procedures used for BNCT differ significantly [9]. Furthermore, because a specialty certification system for physicians engaged in BNCT had already been established by the Japanese Society of Neutron Capture Therapy, the capability survey item for physicians focused on individual information, such as their own specialty and qualifications. The capabilities of medical physicists and radiological technologists were evaluated through self-assessment at three levels. The highest level was 'Implementable and teachable', the second one was 'Implementable' and the lowest was 'Non-implementable'. In this study, the 'Implementable' capability was defined as either ability to take initiatives in processing each work or to implement the process on their own. Furthermore, the survey items covered not only the ability to perform their own duties, but also personal information such as age, academic degree and qualifications. Twelve physicians participated in the survey. Seven medical physicists and seven radiological technologists participated in this survey. To reveal the specialized capabilities for BNCT, other six medical physicists who provide conventional radiotherapy, such as photon therapy

**Table 4. Capability survey for BNCT work items in physician**

| |
|---|
| 1. General information |
| Age |
| Academic degree |
| Specialty certification in a basic field other than radiology |
| 2. Qualification |
| 2–1: If the respondent has specialty certification in a basic field other than radiation oncology. |
| Radiation oncology specialist |
| Specialist in basic field other than radiation oncology |
| Certified physician from Japanese Society of Neutron Capture Therapy |
| Please answer the following question regarding the basic field of medical specialties other than radiation oncology |
| 2–2: If the respondent has specialty certification of the radiation oncology. |
| Certified physician from Japanese Society of Neutron Capture Therapy |

and brachytherapy, but not BNCT were surveyed. As there was only one facility that offered both conventional radiotherapy and BNCT in the same facility, the data for comparison were collected from the six medical physicists belonging to that facility. The study divided the participants into two groups according to their capabilities. Those who responded 'Implementable and teachable' or 'Implementable' were assigned a group, whereas those who responded 'Non-implementable' were assigned to the other group. Furthermore, we asked the candidates what was required to provide the accelerator-based BNCT more safely and effectively.

## Statistical analysis

Chi-square analyses were performed to analyze discrepancies in staff capabilities. The analysis included the responses of medical physicists and radiological technologists. In addition, medical physicists engaged and not engaged in BNCT were also compared to determine the required capabilities based on each BNCT-related work item for BNCT. Continuous variables, such as age, were dichotomized at the median value and analyzed. A $P$-value of $<0.05$ was considered statistically significant.

# RESULTS

## General facility information

Responses to the workload survey were received from all three facilities. The acceptable number of patients who could be treated with BNCT was either two or four per week. Figure 1 shows whether the patients referred for BNCT received it. Only 6–21% of the patients referred to BNCT received it among the three institutions. In many cases, patients were judged ineligible for BNCT without medical consultation; however, more than 60% of those who had medical consultation were judged ineligible. Figure 2 shows the residences of patients treated with BNCT at each facility. Only 30–75% of patients treated with BNCT resided in the same district as the facility. The particular facility that treated more than 10 patients per year had more than a half of those patients visiting from outside the local district to receive BNCT.

## Workload survey

Table 5 presents the workload required per patient treatment based on medical staff's occupation. It should be noted that, in Table 5, the workload of patients who were prepared to undergo BNCT but did not receive it was excluded. The median required workload per patient treatment among three institutions was 55.0 h for all occupations taken together. The median required workload was the highest for medical physicists, reaching 30.0 h followed by radiological technologists (14 h), physicians (7.4 h) and registered nurses (3.6 h). Table 6 presents the details of the workloads required for each occupation. The workloads of the two facilities that were performed as insurance treatment were the smallest and largest, respectively. If the required

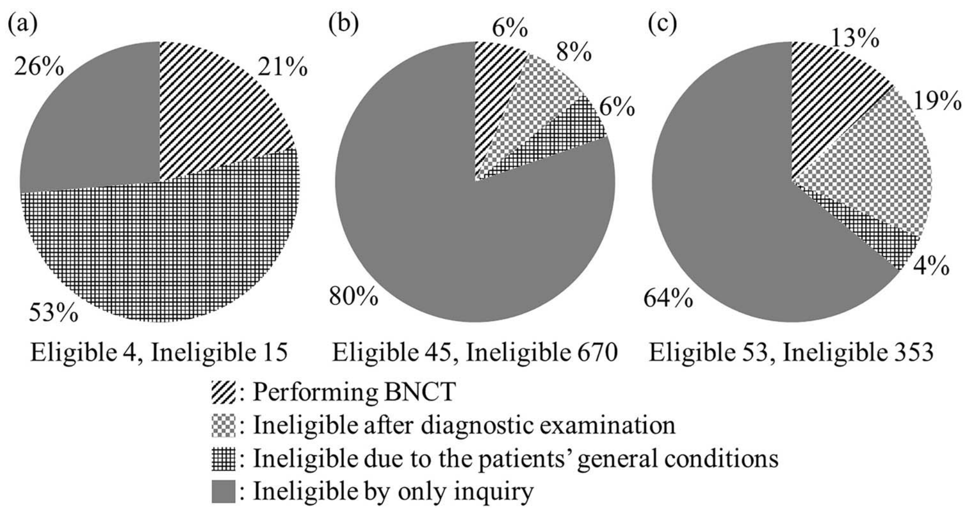


**Fig. 1. Percentage of patients referred to BNCT who received BNCT or not in each facility (a–c).**

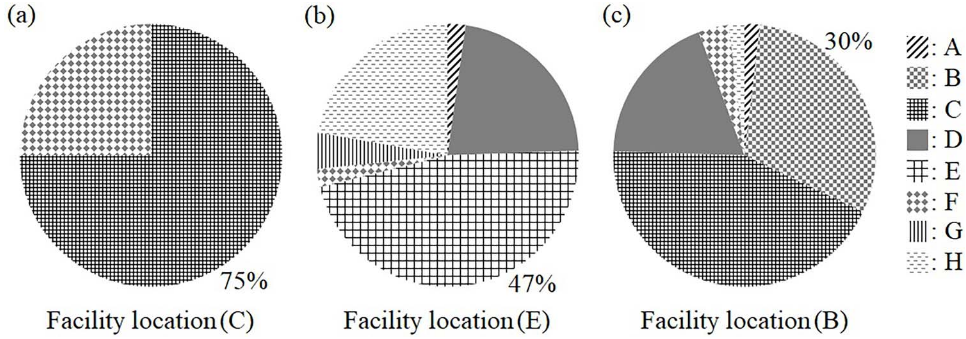


**Fig. 2. The local district of residence of patients who received BNCT in each facility (a–c). The local district was divided into eight (A–H) based on the administrative district of Japan.**

**Table 5. The required workload per a treatment in each occupation**

| Occupation | Required workload per a treatment [h] | |
|---|---|---|
| | Without workload for ineligible patient | With workload for ineligible patient |
| Physician | 7.4 | 10.8 |
| Medical physicist | 30.0 | 33.8 |
| Registered nurse | 3.6 | 4.1 |
| Radiological technologist | 14.00 | 15.9 |

workloads were classified as 'Treatment preparations' and 'QA procedures and the others', they were mostly performed outside treatment days (i.e. 'Treatment day procedures') and reached 75.0% of the required workload. Although, the calculation time required was 9 h per treatment plan, this was excluded from the workload. Furthermore, an additional workload was required for the ineligible patients to determine the eligibility for BNCT. Considering the additional workload for the number of the ineligible patients per week, the typical of required time for physician, medical physicist, registered nurse and radiological technologist, reached 1.5 (+3.4 h), 1.1 (+3.8 h), 1.1 (+0.5 h) and 1.1 (+1.9 h) times, respectively, compared to the required workload for only the eligible patients. Therefore, when the additional workload was considered, the total workload was 1.2 times longer than the required workload.

## Staff capability survey

Table 7 shows the characteristics of medical physicists and radiological technologists. Table 8 shows the capabilities of staff engaged in BNCT as medical physicists or radiological technologists. According to Table 8, the staff could not perform all the BNCT work items. Table 9 shows the capability comparison of the staff engaged in BNCT as medical physicists or radiological technologists, based on the BNCT work items defined in Table 3. Medical physicists tended to handle all works more frequently than radiological technologists. In particular, discrepancies in capabilities between medical physicists and radiological technologists were observed in the work items of treatment planning, QA and quality control (QC) and commissioning, whereas those of treatment preparation, treatment and risk management were comparable. The other analyses are summarized in Supplemental Tables 1–5. A statistically significant difference for the staff capabilities between the facilities where BNCT was covered by insurance and those where it was not was observed in three work items (Supplemental Table 5). In addition, Supplemental Table 6 shows the results of the responses from candidates that are needed to provide the accelerator-based BNCT safely and effectively.

Table 10 shows the capability comparison between medical physicists engaged in BNCT and those not engaged in BNCT based on the BNCT's work items defined in Table 3. Discrepancies in capabilities were observed in almost all the work items (88%, 22/25). Furthermore, all the work items, which had statistically significant differences in the comparison between medical physicists and radiological technologists, also maintained statistically significant differences between these two groups.

Table 11 shows the responses of physicians engaged in BNCT. The specialty of physicians engaged in BNCT was not only radiation oncology but also other fields. In addition, most physicians were certified by the Japanese Society of Neutron Capture Therapy to conduct BNCT.

## DISCUSSION

This is the first study on the required workload and staff capabilities for accelerator-based BNCT reflecting actual clinical situations. In other radiotherapies, such as photon therapy, the required workload has been reported in some organizations and reports, and a staffing model was developed [10–15]. This was a result of the standardization of each work-related item. For example, the work items for QA and QC were standardized in photon therapy, and typical procedures were indicated [16,17]. However, accelerator-based BNCT is a recently developed radio-therapeutic technique. Hence, the work items and procedures for QA and QC in the accelerator-based BNCT depend on each facility, and there were large variations between those facilities owing to the lack of standardization for each work item (Table 6). As the reports related to standardization were limited and insufficient to standardize the work items for BNCT [18,19], standardization remains one of the most important issues in BNCT and is necessary to reveal the required data. This study is expected to contribute to the standardization of BNCT because the required workload was

**Table 6. Responses of workload survey items**

| Work task | Main occupations | Work category (1–3)[a] | Spending time on each patient [min] Median (range) |
|---|---|---|---|
| 1. Clinical work | | | |
| Treatment appointments | MD | 1 | 45 (15–60) |
| Conferences in the radiation oncology department | MD | 1 | 45 (30–585) |
| Preliminary explanation of taking CT images and irradiation | RT | 1 | 15 (10–30) |
| Immobilization devices selection | MP, RT | 1 | 30 (0–45), 30 (0–45) |
| Additional time for customized shell fabrication | MP, RT | 1 | 45 (30–112.5), 45 (30–112.5) |
| Additional time for vacuum cushion creation | MP, RT | 1 | 45 (30–112.5), 45 (30–112.5) |
| Additional time for complicated treatment posture | MP, RT | 1 | 60 (45–180), 60 (45–180) |
| Taking plain CT imaging with the immobilization devices | MP, RT | 1 | 60 (15–60), 60 (15–60) |
| Additional time for contrast-enhanced CT | MP, RT | 1 | 0 (0–30), 0 (0–30) |
| Image import | MP | 1 | 10 (10–20) |
| Image fusion | MP | 1 | 30 (15–120) |
| Contouring | MP | 1 | 120 (120) |
| Treatment planning | MP | 1 | 100 (60–360) |
| Calculation time for dose distribution | (MP)[b] | 1 | 540 (390–6240) |
| Consideration of activation for implant metal | MP | 1 | 0 (0–10) |
| Plan approval | MD | 1 | 30 (30–40) |
| Plan check | MP | 1 | 60 (30–60) |
| Irradiation preparation | MP, RT, RN | 2 | 240 (30–240), 120 (15–120), 120 (15–120) |
| Irradiation | MP, RT, RN | 2 | 192 (120–240), 192 (120–240), 96 (60–120) |
| Treatment data management | MD, MP | 3 | 100 (15–120), 100 (15–120) |
| 2. QA/QC work | | | |
| 2–1. Patient-specific work | | | |
| Neutron measurement using activation foil method | MP | 3 | 80 (0–90) |
| Gamma-ray measurement using TLD or glass dosimeter | MP | 3 | 60 (0–60) |
| Confirmation of dose verification and report preparation | MP | 3 | 30 (0–60) |
| 2–2. Treatment machine[c] | | | |
| Daily QA of treatment machine | MP, RT | 3 | 17.5 (5–30), 17.5 (5–30) |
| Weekly QA of treatment machine | MP, RT | 3 | 93.8 (7.5–180), 93.8 (7.5–180) |
| QA for replacement of consumable parts of treatment machine | MP, RT | 3 | 22.5 (0–45), 22.5 (0–45) |
| Other QA of treatment machine | MP, RT | 3 | 37.5 (15–135), 37.5 (15–135) |
| 2–3. Planning CT equipment | | | |
| Daily QA of CT equipment | MP, RT | 3 | 5 (2.5–7.5), 5 (2.5–7.5) |
| Weekly QA of CT equipment | MP, RT | 3 | 5.6 (3.8–7.5), 5.6 (3.8–7.5) |
| Other QA of CT equipment | MP, RT | 3 | 1.3 (0–2.5), 1.3 (0–2.5) |
| 3. Radiation management work | | | |
| Control of residual radioactivity | MP | 3 | 15 (5–15) |
| Quantification of radioactivity of instruments/irradiated materials | MP | 3 | 15 (5–15) |
| Radiation contamination test | MP | 3 | 10 (5–10) |
| 4. General work | | | |
| Development of BNCT (including patient recruitment) | MD, MP | 3 | 150 (60–450), 150 (60–450) |
| Other BNCT implementation-related work (such as item and treatment schedule management, and follow-up data acquisition after BNCT, etc.) | MD, MP | 3 | 75 (30–450), 75 (30–450) |
| Others (radiation safety and human resource and department managements) | MP, RT | 3 | 90 (45–165), 90 (45–165) |

The workload was assumed that the BNCT was performed for two patients every week.
MD = medical doctor, MP = medical physicist, RN = registered nurse, RT = radiological technologist
[a]Work was categorized as follows: 1. Treatment preparations, 2. Treatment day procedures, 3. QA procedures and the others. [b]Calculation time was excluded from the workload of medical physicist. [c]Collected only at medical institutions that provide insurance treatment.

**Table 7. Characteristics of participants engaged as either medical physicist or radiological technologist**

| General information | *n* (%) |
|---|---|
| Age [years], median (range) | 36 (28–63) |
| Academic degree | |
| <Master degree | 6 (42.9) |
| ≧Master degree (Master and Ph.D.) | 8 (57.1) |
| Office organization | |
| Medical physicist | 7 (50.0) |
| Radiation technologist | 7 (50.0) |
| Years of experience in radiotherapy | |
| <15 years | 9 (64.3) |
| ≧15 years | 5 (35.7) |

investigated based on the BNCT's work items while considering actual clinical situations. Furthermore, a previous report by the International Atomic Energy Agency proposed a minimum number of professionals required for BNCT [19]. However, the report did not reflect actual clinical conditions, such as considering indication disease and clinical operations, etc., because it did not adequately consider the workload and staff capabilities. Therefore, this study provides workloads that more adequately reflects actual clinical conditions.

This study also revealed the capabilities of the staff engaged in clinical work. As shown in Table 6, the BNCT's work items were adequately assigned to each occupation by referring to conventional radiotherapies [10]. However, the assigned workload for each occupation requires highly specialized BNCT knowledge and skills. According to Table 8, very few medical physicists and radiological technologists engaged in BNCT, have the knowledge and skills to perform all the tasks associated with BNCT. As shown in Table 9, the medical physicists tended to handle any work, although their characteristics differed from those of radiological technologists (Supplemental Table 1). Thus, for medical physicists engaged in BNCT, it is that their respective duties be performed by understanding the characteristics of their entire work. Medical physicists also had specialized BNCT knowledge and skills, especially for the work items of treatment planning, QA and QC, and commissioning, which were then considered the required capabilities of the medical physicist engaged in BNCT. Furthermore, based on Table 10, most of the work items (88%) could not be performed by medical physicists who were not engaged in BNCT, and the specialized knowledge and skills required for medical physicists engaged in BNCT were not derived from their experiences with conventional radiotherapies. However, there are many things to be learned from conventional radiotherapy that are important for BNCT. For example, the dose evaluations in BNCT adopt the relative biological effectiveness-weighted dose (i.e. the photon-equivalent dose), and the tolerance dose and adverse events related to BNCT are also estimated based on the dose evaluations with reference to reports on conventional radiotherapies [4,6–8,20]. Additionally, previous studies have investigated the adverse events in a specified organ after BNCT by comparing the delivered dose to that organ [6,7]. Because the number of BNCT cases is limited (Fig. 1), it is important for the further clinical development of BNCT to utilize clinical data from conventional radiotherapies. Therefore, it is necessary to develop a specialized educational program that includes BNCT and conventional radiotherapy and to establish a certification system for those with specialized knowledge and skills in BNCT to treat patients safely and effectively.

Patients might be more likely to undergo BNCT if it were covered by insurance, but this was not considered in this study due to the limited number of participating facilities. Actually, more than 60% of patients judged ineligible with only inquiry at the facilities in which BNCT was performed as the insurance treatment, while it was 26% at the facility in which BNCT was performed as the non-insurance treatment. However, the results indicated that the BNCT performed as the insurance treatment or not did not have any impact on the workload or capabilities of the medical staff. According to Supplemental Table 5, although the significant difference for the staff capabilities between the facilities where BNCT was covered by insurance and those where it was not observed in three work items, those items were independent of cancer type. Since this questionnaire surveyed basic capabilities for performing BNCT, there might be some differences in each cancer type, but the knowledge, skills and experience required to acquire the capabilities were considered to be basically comparable. Furthermore, the workloads of the two facilities that were performed as insurance treatment were the smallest and largest, respectively. Therefore, the workload was also independent of cancer type (Table 6).

In August 2022, there were only 30 physicians certified for BNCT by the Japanese Society for Neutron Capture Therapy. As shown in Table 11, only 16.7% of certified physicians (5/30) were engaged in BNCT at the time of the questionnaire study. Many certified physicians have worked on BNCT with nuclear reactors in the past, but they are not currently engaged for various reasons. Hence, the number of physicians capable of determining the BNCT indication was much smaller. Furthermore, Table 11 shows that the certified physicians had diverse specialties. According to a previous report [19], as BNCT can deliver an extremely large dose during a single fraction, it was necessary that a close clinical collaboration between the radiation oncologist and a specialist physician was required for BNCT. Therefore, BNCT requires more specific knowledge and expertise than conventional radiotherapy, owing to its characteristic features.

Only a small percentage (6–21%) of the patients who consulted a physician for BNCT indications actually received BNCT (Fig. 1). There was one facility in which more than 600 inquiries per year from ineligible patients. In this study, it was difficult to adequately reflect these inquiries, especially from other hospitals, on the workload. This is because the required workload is expected to vary depending on a patient's condition and situation. Hence, this study excluded inquiries from ineligible patients regarding workload. However, there were facilities where BNCT indications were determined after tentative treatment planning, and the dose distribution was created for almost all cases using CT images. In such cases, an extremely high additional workload is required. Therefore, the study revealed that physicians spent considerable workload on consulting with patients who were not only eligible but also ineligible, and medical physicists were also involved in tentative treatment planning, in which the required workload was comparable to the actual treatment planning for determining the BNCT indication (in Table 6). Hence, this study suggests that a greater workload is required to determine the indication for BNCT compared to conventional radiotherapies.

**Table 8. Staff capabilities engaged in BNCT as the medical physicist or the radiological technologist**

| Work category[a] | Work contents | *n* (%) | |
|---|---|---|---|
| | | Implementable | Non-implementable |
| 1 | Taking planning CT (including creation of immobilization devices) | 12 (85.7) | 2 (14.3) |
| 2 | Contouring of organ-at-risks on treatment planning | 9 (64.3) | 5 (35.7) |
| 2 | Create treatment planning | 8 (57.1) | 6 (42.9) |
| 2 | Treatment planning check in terms of the medical physics | 7 (50.0) | 7 (50.0) |
| 2 | Confirmation of induced radionuclide | 5 (35.7) | 9 (64.3) |
| 2 | Treatment planning approval in terms of the medical physics | 7 (50.0) | 7 (50.0) |
| 3 | Data input to BNCT device and peripheral device | 11 (78.6) | 3 (21.4) |
| 3 | Treatment planning check in terms of the feasibility and the medical safety | 12 (85.7) | 2 (14.3) |
| 3 | Management of treatment schedule | 10 (71.4) | 4 (28.6) |
| 3 | Management for necessary items (including consumables, required for inductively coupled plasma device, etc.) | 4 (28.6) | 10 (71.4) |
| 3 | Confirmation of boron concentration validity in a patient | 5 (35.7) | 9 (64.3) |
| 3 | Determination of final monitor unit reflecting the actual boron concentration in a patient | 9 (64.3) | 5 (35.7) |
| 4 | Patient setup and image guidance at the treatment | 12 (85.7) | 2 (14.3) |
| 4 | Determination of the final position at the treatment | 11 (78.6) | 3 (21.4) |
| 5 | Neutron measurement for QA and QC procedures | 9 (64.3) | 5 (35.7) |
| 5 | Contaminated gamma-ray measurement for QA and QC procedures | 9 (64.3) | 5 (35.7) |
| 5 | QA of BNCT device | 10 (71.4) | 4 (28.6) |
| 5 | Proposing the countermeasure based on the results of QA/QC | 11 (78.6) | 3 (21.4) |
| 6 | Management of the residual radioactivity | 9 (64.3) | 5 (35.7) |
| 6 | Quantification of radioactivity of instruments/irradiated materials | 9 (64.3) | 5 (35.7) |
| 6 | Radiation contamination test | 8 (57.1) | 6 (42.9) |
| 7 | Implementation of new or updated BNCT device | 4 (28.6) | 10 (71.4) |
| 7 | Implementation of new or updated treatment planning system for BNCT | 6 (42.9) | 8 (57.1) |
| 7 | Implementation of new or updated peripheral devices | 6 (42.9) | 8 (57.1) |
| 8 | Risk management of BNCT | 9 (64.3) | 5 (35.7) |

[a]Work was categorized as follows: 1. Simulation for treatment, 2. Treatment planning, 3. Treatment preparation, 4. Treatment, 5. QA and QC, 6. Radiation control, 7. Commissioning, 8. Risk management.

Although the degree depended on each facility, all of the facilities received inquiries about the eligibility for BNCT from both local and outside districts. Therefore, the potential demand for BNCT was expected to be much greater than the actual number of BNCT performed, and it was revealed that patients from all over the country visited BNCT facilities, which existed only in limited areas (Fig. 2). In addition, it was also estimated that the percentage of patients who traveled to distant BNCT facilities was not high because most of the patients who received BNCT at each facility lived in or near the local district of the BNCT facility location. This suggests that the potential demand for applying BNCT was not satisfied in areas where BNCT facilities do not exist. Furthermore, as research and development of BNCT continue, if the indications for BNCT expand, the demand for BNCT is expected to increase further. Therefore, installing an accelerator-based BNCT system in each local district will reduce the burden on patients traveling to distant hospitals for BNCT. Furthermore, it will help medical institutions operate their BNCT systems efficiently to satisfy the demand for BNCT.

This study has the following limitations. The number of facilities and respondents to the staff capability survey was small, and the facility location and status of providing BNCT (i.e. insurance treatment or not, etc.) had variations. According to Fig. 2, at the facility located in a local city, the largest proportion of patients who lived in other districts were treated (70%), while it was the smallest at the facility located in the capital city (25%). This might relate not only the facility location, but also the status of BNCT treatment. Furthermore, only Japanese three facilities satisfied the eligibility requirement in our survey although the role and scope of the work in each occupation might depend on related regulations in each country. Therefore, although we identified as many work items required for clinical BNCT as possible in this study by considering two different types of accelerator-based BNCT devices, which have already been clinically implemented, and established sophisticated staffing systems, we expect new reports from other institutions using other devices and other countries to discuss the required workload and capabilities in detail.

**Table 9. Univariate analysis for the staff capabilities in each BNCT work between the medical physicists and the radiological technologists**

| Work category[a] | Work contents | Medical physicist ($n = 7$) | | Radiological technologist ($n = 7$) | | *P*-value |
|---|---|---|---|---|---|---|
| | | Implementable *n* (%) | Non-implementable *n* (%) | Implementable *n* (%) | Non-implementable *n* (%) | |
| 1 | Taking planning CT (including creation of immobilization devices) | 6 (85.7) | 1 (14.3) | 6 (85.7) | 1 (14.3) | 1 |
| 2 | Contouring of organ-at-risks on treatment planning | 7 (100) | 0 (0) | 2 (28.6) | 5 (71.4) | 0.005* |
| 2 | Create treatment planning | 7 (100) | 0 (0) | 1 (14.3) | 6 (85.7) | 0.001* |
| 2 | Treatment planning check in terms of the medical physics | 6 (85.7) | 1 (14.3) | 1 (14.3) | 6 (85.7) | 0.008* |
| 2 | Confirmation of induced radionuclide | 5 (71.4) | 2 (28.6) | 0 (0) | 7 (100) | 0.005* |
| 2 | Treatment planning approval in terms of the medical physics | 6 (85.7) | 1 (14.3) | 1 (14.3) | 6 (85.7) | 0.008* |
| 3 | Data input to BNCT device and peripheral device | 6 (85.7) | 1 (14.3) | 5 (71.4) | 2 (28.6) | 0.515 |
| 3 | Treatment planning check in terms of the feasibility and the medical safety | 7 (100) | 0 (0) | 5 (71.4) | 2 (28.6) | 0.127 |
| 3 | Management of treatment schedule | 5 (71.4) | 2 (28.6) | 5 (71.4) | 2 (28.6) | 1 |
| 3 | Management for necessary items (including consumables, required for inductively coupled plasma device, etc.) | 2 (28.6) | 5 (71.4) | 2 (28.6) | 5 (71.4) | 1 |
| 3 | Confirmation of boron concentration validity in a patient | 3 (42.9) | 4 (57.1) | 2 (28.6) | 5 (71.4) | 0.577 |
| 3 | Determination of final monitor unit reflecting the actual boron concentration in a patient | 6 (85.7) | 1 (14.3) | 3 (42.9) | 4 (57.1) | 0.094 |
| 4 | Patient setup and image guidance at the treatment | 6 (85.7) | 1 (14.3) | 6 (85.7) | 1 (14.3) | 1.000 |
| 4 | Determination of the final position at the treatment | 6 (85.7) | 1 (14.3) | 5 (71.4) | 2 (28.6) | 0.515 |
| 5 | Neutron measurement for QA and QC procedures | 7 (100) | 0 (0) | 2 (28.6) | 5 (71.4) | 0.005* |
| 5 | Contaminated gamma-ray measurement for QA and QC procedures | 7 (100) | 0 (0) | 2 (28.6) | 5 (71.4) | 0.005* |
| 5 | QA of BNCT device | 7 (100) | 0 (0) | 3 (42.9) | 4 (57.1) | 0.018* |
| 5 | Proposing the countermeasure based on the results of QA/QC | 7 (100) | 0 (0) | 4 (57.1) | 3 (42.9) | 0.051 |
| 6 | Management of the residual radioactivity | 5 (71.4) | 2 (28.6) | 4 (57.1) | 3 (42.9) | 0.577 |
| 6 | Quantification of radioactivity of instruments/irradiated materials | 6 (85.7) | 1 (14.3) | 3 (42.9) | 4 (57.1) | 0.094 |
| 6 | Radiation contamination test | 5 (71.4) | 2 (28.6) | 3 (42.9) | 4 (57.1) | 0.280 |
| 7 | Implementation of new or updated BNCT device | 3 (42.9) | 4 (57.1) | 1 (14.3) | 6 (85.7) | 0.237 |
| 7 | Implementation of new or updated treatment planning system for BNCT | 5 (71.4) | 2 (28.6) | 1 (14.3) | 6 (85.7) | 0.031* |
| 7 | Implementation of new or updated peripheral devices | 5 (71.4) | 2 (28.6) | 1 (14.3) | 6 (85.7) | 0.031* |
| 8 | Risk management of BNCT | 5 (71.4) | 2 (28.6) | 4 (57.1) | 3 (42.9) | 0.577 |

The '*' indicates a variable that has a significant difference.
[a]Work was categorized as follows: 1. Simulation for treatment, 2. Treatment planning, 3. Treatment preparation, 4. Treatment, 5. QA and QC, 6. Radiation control, 7. Commissioning, 8. Risk management.

**Table 10. Univariate analysis for the staff capabilities in each BNCT work between the medical physicists engaged in BNCT and those not engaged in BNCT**

| Work category[a] | Work contents | Engaged in BNCT ($n = 7$) | | Not engaged in BNCT ($n = 6$) | | *P*-value |
|---|---|---|---|---|---|---|
| | | Implementable *n* (%) | Non-implementable *n* (%) | Implementable *n* (%) | Non-implementable *n* (%) | |
| 1 | Taking planning CT (including creation of immobilization devices) | 6 (85.7) | 1 (14.3) | 1 (16.7) | 5 (83.3) | 0.013* |
| 2 | Contouring of organ-at-risks on treatment planning | 7 (100) | 0 (0) | 2 (33.3) | 4 (66.7) | 0.009* |
| 2 | Create treatment planning | 7 (100) | 0 (0) | 0 (0) | 6 (100) | < 0.001* |
| 2 | Treatment planning check in terms of the medical physics | 6 (85.7) | 1 (14.3) | 0 (0) | 6 (100) | 0.002* |
| 2 | Confirmation of induced radionuclide | 5 (71.4) | 2 (28.6) | 0 (0) | 6 (100) | 0.008* |
| 2 | Treatment planning approval in terms of the medical physics | 6 (85.7) | 1 (14.3) | 0 (0) | 6 (100) | 0.002* |
| 3 | Data input to BNCT device and peripheral device | 6 (85.7) | 1 (14.3) | 0 (0) | 6 (100) | 0.002* |
| 3 | Treatment planning check in terms of the feasibility and the medical safety | 7 (100) | 0 (0) | 0 (0) | 6 (100) | < 0.001* |
| 3 | Management of treatment schedule | 5 (71.4) | 2 (28.6) | 0 (0) | 6 (100) | 0.008* |
| 3 | Management for necessary items (including consumables, required for inductively coupled plasma device, etc.) | 2 (28.6) | 5 (71.4) | 0 (0) | 6 (100) | 0.154 |
| 3 | Confirmation of boron concentration validity in a patient | 3 (42.9) | 4 (57.1) | 0 (0) | 6 (100) | 0.067 |
| 3 | Determination of final monitor unit reflecting the actual boron concentration in a patient | 6 (85.7) | 1 (14.3) | 0 (0) | 6 (100) | 0.002* |
| 4 | Patient setup and image guidance at the treatment | 6 (85.7) | 1 (14.3) | 1 (16.7) | 5 (83.3) | 0.013* |
| 4 | Determination of the final position at the treatment | 6 (85.7) | 1 (14.3) | 0 (0) | 6 (100) | 0.002* |
| 5 | Neutron measurement for QA and QC procedures | 7 (100) | 0 (0) | 1 (16.7) | 5 (83.3) | 0.002* |
| 5 | Contaminated gamma-ray measurement for QA and QC procedures | 7 (100) | 0 (0) | 1 (16.7) | 5 (83.3) | 0.002* |
| 5 | QA of BNCT device | 7 (100) | 0 (0) | 0 (0) | 6 (100) | < 0.001* |
| 5 | Proposing the countermeasure based on the results of QA/QC | 7 (100) | 0 (0) | 0 (0) | 6 (100) | < 0.001* |
| 6 | Management of the residual radioactivity | 5 (71.4) | 2 (28.6) | 0 (0) | 6 (100) | 0.008* |
| 6 | Quantification of radioactivity of instruments/irradiated materials | 6 (85.7) | 1 (14.3) | 1 (16.7) | 5 (83.3) | 0.013* |
| 6 | Radiation contamination test | 5 (71.4) | 2 (28.6) | 0 (0) | 6 (100) | 0.008* |
| 7 | Implementation of new or updated BNCT device | 3 (42.9) | 4 (57.1) | 0 (0) | 6 (100) | 0.067 |
| 7 | Implementation of new or updated treatment planning system for BNCT | 5 (71.4) | 2 (28.6) | 0 (0) | 6 (100) | 0.008* |
| 7 | Implementation of new or updated peripheral devices | 5 (71.4) | 2 (28.6) | 0 (0) | 6 (100) | 0.008* |
| 8 | Risk management of BNCT | 5 (71.4) | 2 (28.6) | 0 (0) | 6 (100) | 0.008* |

The '*' indicates a variable that has a significant difference.
[a]Work was categorized as follows: 1. Simulation for treatment, 2. Treatment planning, 3. Treatment preparation, 4. Treatment, 5. QA and QC, 6. Radiation control, 7. Commissioning, 8. Risk management.

In conclusion, this study focused on the required workload and staff capabilities for providing accelerator-based BNCT considering actual clinical conditions. The required workload depended on each occupation and was the highest among medical physicists. Furthermore, as BNCT can be performed with only a small percentage of patients who consult the physician for BNCT indications, the workload for the ineligible patients was found to be extremely high to determine eligibility compared to conventional radiotherapy. In the

**Table 11. Characteristics of respondents engaged as a physician**

| 1. General information | *n* (%) |
|---|---|
| Age [years], median (range) | 48.5 (34–71) |
| Academic degree | |
| <Ph. D. | 0 (0) |
| = Ph. D. | 12 (100) |
| Specialty certification in a basic field other than radiology | |
| Yes | 3 (25.0) |
| No | 9 (75.0) |
| 2. Qualification | |
| 2–1. If the respondent has specialty certification in a basic field other than radiation oncology. | |
| Radiation oncology specialist | |
| Yes | 0 (0) |
| No | 3 (100) |
| Specialist in basic field other than radiation oncology | |
| Yes | 3 (100) |
| No | 0 (0) |
| Certified physician from Japanese Society of Neutron Capture Therapy | |
| Yes | 2 (66.7) |
| No | 1 (33.3) |
| Please answer the following question regarding the basic field of medical specialties other than radiation oncology | |
| Neurosurgery | 2 (66.7) |
| Head and neck surgery, otolaryngology | 1 (33.3) |
| 2–2. If the respondent has specialty certification of the radiation oncology. | |
| Certified physician from Japanese Society of Neutron Capture Therapy | |
| Yes | 3 (33.3) |
| No | 6 (66.7) |

survey of staff capabilities, each occupation required specialized skills to provide BNCT, which are not acquired from providing conventional radiotherapy for a long period. In addition, the number of staff members with the required capabilities is limited. Therefore, it is necessary to establish an educational program and certification system for the required skills for each occupation to safely and effectively provide BNCT to patients. It may focus on physicians and medical physicists because their requirements are unique. Furthermore, the implementation of an accelerator-based BNCT system in each local district is expected to guarantee equal opportunities to receive BNCT, which will also help efficiently operate BNCT systems and satisfy its demand.

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## CONFLICT OF INTEREST

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## SUPPLEMENTARY DATA

Supplementary data are available at *Journal of Radiation Research* online.

## PRESENTATION AT A CONFERENCE

Not presented at any conference.

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