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Rapid and safe installation of linear accelerators using vendor commissioning support and additional user commissioning

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ABSTRACT

Background*:** The successful installation of linear accelerators (LINACs) depends on operator skill and experience, and its optimization can be further improved using vendor commissioning support. To facilitate the introduction of LINAC, Elekta provides commissioning support through Accelerated Go Live (AGL) using representative beam data. This study aimed to evaluate the effective commissioning of LINAC-assisted AGL complemented by additional measurements conducted by a user. ***Materials and Methods: Output doses were measured within a field size of > 3 cm2 using a single chamber with AGL and within a field size of > 2 cm^2 using three types of optimal chambers based on the field size adopted by the user. In all cases, the differences between the measured and calculated output doses were maintained at < 2%. ***Results:*** The accuracy of couch modeling was evaluated by measuring arc irradiation for three different field sizes, with the electron density value assigned as a dose difference of <2% between the measured and calculated values at 2% for all energies and field size of >3 cm2. Additionally, imaging scan parameters for cone beam computed tomography were optimized to reduce the radiation dose, in comparison to the initial vendor settings, by referencing IEC 60601-2-44 standards and examining results from neighboring facilities. ***Conclusions:*** AGL proved to be effective as a temporary check, but additional commissioning efforts by the user were necessary for a more thorough evaluation and more appropriate initiation, aligning with established clinical practices.

INTRODUCTION

Over the years, significant advancements have been noted in radiotherapy technologies of linear accelerators (LINACs). The introduction of new equipment necessitates in-depth understanding and skills to effectively implement new technologies and optimize quality control and clinical processes [(1)].

Recent developments in the field have seen the provision of reference beam data (RBD) and beam matching services through vendor commissioning support [(2)], thus contributing to the rapid clinical introduction of higher-precision radiotherapy such as stereotactic radiotherapy [(3)]. Beam matching facilitates the introduction of standardized radiation therapy within specified tolerance for a common set of baseline parameters, thus eliminates the need for certain beam data measurements to be registered with a radiation treatment planning system (RTPS) [(3)]. An example of an ultra-efficient installation and commissioning program is Elekta's Accelerated Go Live (AGL), designed to function as a commissioning support system. It evaluates and adjusts a commissioning item, such as output dose and factor, beam profiles, and multileaf collimator (MLC) parameters, in approximately 3 days [(4)].

While numerous commissioning items are essential for conducting analyses in accordance with the RTPS quality assurance guidelines of the American Association of Physicists in Medicine, European Society for Therapeutic Radiology and Oncology, and International Atomic Energy Agency, the final decision on commissioning items is made by the user [(5-7)]. Deviations from the reference dose between the output of the LINAC and the planned dose of the RTPS owing to insufficient evaluation and commissioning can result in large systematic errors in volumetric modulated arc therapy and stereotactic radiotherapy [8,9]. Thus, although vendor commissioning programs are effective for rapid introduction of LINACs, users need to perform additional evaluations to mitigate the risks associated with large systematic errors [2,10,11].

During the introduction process for LINACs, attenuation of a table couch is defined as the difference between RTPS and LINAC measurements, which are not covered by AGL. To achieve precise attenuation adjustments based on detailed measurements, table couch of RTPS is recommended [12,13]. In addition, the use of cone beam computed tomography (CBCT) systems for image-guided radiotherapy has increased, although radiation exposure reduction remains an important issue [14].

To the best of our knowledge, no study has considered vendor commissioning programs and additional evaluation by users. Thus, this study aimed to evaluate the rapid and safe installation of LINAC, with a focus on the usefulness and risks of AGL in clinical operation. In this study, the collaborative initiative between vendors and users represents a novel approach to combine experience, technology, and knowledge to ensure safe and efficient introduction of new equipment. This novel initiative is expected to aid in establishing a commissioning method for a safer and faster introduction of LINAC using reference beam matching and thus facilitate commissioning support.

MATERIALS AND METHODS

Method

The LINAC introduction was performed using Versa HD (Elekta Oncology Systems, Crawley, UK) between October 2022 and January 2023, and RBD and AGL were used. The positions of the MLC and JAW before the AGL were adjusted using split-field and strip tests. The study flow is shown in figure 1.

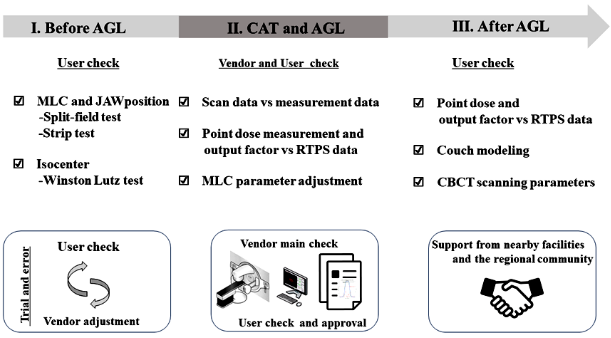

Figure 1. Study flow chart.AGL, accelerated go live; CAT, commissiong and acceptance test; MLC, multileaf collimator; RTPS, radiation treatment planning system; CBCT, cone beam computed tomography.

Beam matching of AGL using RBD and measured data

The beam was matched by the vendor and facility personnel using IC Profiler (Sun Nuclear, Melbourne, FL) and BeamPro (Elekta Oncology Systems, Crawley, UK). IC Profiler was used to measure the profile and beam quality, whereas BeamPro was used for comparisons of the RBD with the measured profile. The RBD of the erector treatment machine was adjusted to match <1% of the beam profile of the irradiated field, with dimensions of 30 × 30 cm^2 at off axis distances of 7 and 10 cm from the profile considered as an acceptable level.4

The difference between the calculated and measured percentage depth dose (PDD) and off center ratio (OCR) were set as < ±2% and ~< ±4, respectively, according to the measurement positions (i.e., center, high dose, low gradient) for calculation algorithms [X-ray Voxel Monte Carlo (XVMC)]. Further, collapsed cone convolution (CCC) was performed using RTPS Monaco® (Elekta AB, Stockholm, Sweden, V5.40.01). The differences in PDD and OCR between the calculated and measured values were evaluated using gamma analysis by varying the dose difference and distance-to-agreement to 2 mm and 2%, respectively [9]. Subsequently, the measured data were used in CC13 ionization chambers (IBA Dosimetry, Schwarzenbruck, Germany) and a 3D Scanner (Sun Nuclear, Melbourne, FL). The output factor was adjusted as per the requirement of < ±2% and < ±1% of the goal.

User evaluation of output dose after AGL

We evaluated the lack of commissioning items in AGL. The difference between the measured and calculated output dose was evaluated in varying irradiation field sizes (2×2, 3×3, 4×4, 5×5, 10×10, 20×20, and 30×30 cm^2). A small irradiation field size of < 5×5 cm^2 was used to measure CC04 ionization chambers (IBA Dosimetry, Schwarzenbruck, Germany) and a 3D Scanner, whereas an irradiation field size of < 10×10 cm^2 was used to measure Farmer ionization chambers (IBA Dosimetry, Schwarzenbruck, Germany) and a 3D Scanner.

User evaluation of table couch attenuation after AGL

AGL does not evaluate the attenuation of couch. Therefore, the user measured the attenuation of the couch for five gantry angles (105°, 120°, 140°, 160°, and 180°), an irradiation field size of 10×10 cm^2 using a water phantom (Tough water WE211, Kyoto Kagaku Co., Ltd. Kyoto, Japan), and a Farmer-type dosimeter. The measured output doses for the attenuation of the couch were compared with the calculated doses for various electron densities relative to water (RED), such as those of carbon fiber (0.4, 0.5, 0.6, and 0.7) and carbon foam (0.01, 0.02,

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0.03, 0.04, and 0.05). The comparison was conducted at 4, 6, and 10 MeV with flattening filter and 6 and 10 MeV without flattening filter. The difference between the measured and calculated doses of attenuation of couch was evaluated for each RED, where the approximation values were selected as a dose difference < 1%, while using a code that eliminated the possibility of overdose. In addition, we measured the couch absorption for three field irradiation sizes (3×3, 5×5, and 10×10 cm^2) using four rotation irradiations (rotational angles in the range of 180° -100° , 0°-100°, 0°- 280°, and 180°- 260°). Moreover, the measured dose was used to evaluate the calculated dose for approximation of two values of attenuation of couch.

Setting of scanning parameters for CBCT

The facility personnel consulted the neighboring facilities regarding the scanning parameters for CBCT. The scanning parameters for CBCT were pre-registered as temporary conditions according to IEC 60601-2-44 (2009) reference of the neighboring facility that was verified in advance.

RESULTS

The results of the AGL and user measurements are presented in Table 1. The initial MLC and JAW positions were properly adjusted through by evaluating the results of the split-field and strip tests. The difference between the RBD and the measured output dose was < 1% at off axis distances of 7 and 10 cm and in an irradiation field size of 30 × 30 cm^2. The RBD and modeling beam profiles were adjusted within the reference values in Monte Carlo (MC) and CC. In AGL, the output factor was within 2% in CCC and 1% in MC. In the additional measurements performed after AGL, the output doses in small irradiation field sizes of <5×5 cm^2 and >10×10 cm^2 were < 2% and < 1%, respectively. In CCC, the difference between the measured and calculated doses for a 30×30 cm^2 irradiation field size was >1.0% for depths of 10 and 20 cm (table 1). In CCC and MC, AGL in case of PDD and OCR for a 30×30 cm^2 irradiation field size at 6 MV exhibited a relationship (figure 2). For AGL in case of OCR for depths of 5 cm, the OCR exhibited a gamma passing rate of 2%/2 mm > 1.0 in the range of -10 cm to12 cm (position) for both CCC and MC (figure 2). Figure 3 shows the evaluation of the attenuation of couch for 6 MV. The difference in the output dose of attenuation between the calculated and measurement doses of couch were < ±3.5% for RED of couch (carbon fiber: 0.4, 0.5, 0.6, and 0.7; with carbon foam: 0.01, 0.02, 0.03, 0.004, and 0.05). Based on the result of each angle and rotating irradiation, the RED was determined as 0.6 for carbon fiber and as 0.03 with foam, with no negative values within 0%–2% for all angles and energies. The scanning parameters for CBCT were registered with an average reduction in exposure of approximately one-tenth (average computed tomography dose index: 0.94) from the initial values (average computed tomography dose index: 18.53) and were ready before the clinical examination.

Table 1. Results of benchmark for AGL and additional user check.

			AGL		Additional user check	
SSD (cm)	Field size (cm^2)	Depth (cm)	Difference between calculation and measurement dose (%)			
			CCC	MC	CCC	MC
90.0	2×2	10.0	-	-	-2.06	-0.80
90.0	3×3	10.0	-1.11	-0.59	-1.78	0.66
90.0	4×4	10.0	-	-	-0.73	-0.22
90.0	5×5	10.0	-0.07	0.44	-0.03	0.54
90.0	7×7	10.0	-	-	-0.07	-0.07
90.0	10×10	10.0	-0.02	0.07	0.03	0.16
90.0	15×15	10.0	-	-	-0.32	-0.08
90.0	20×20	10.0	-	-	0.12	0.12
90.0	30×30	10.0	1.32	0.88	1.22	0.77, -0.54
90.0	2×2	5.0,15.0	-	-	-0.44, -2.20	-0.14, -1.13
90.0	3×3	5.0,15.0	-	-	-0.38, -1.72	0.12, -0.70
90.0	4×4	5.0,15.0	-	-	0.22, -1.00	0.65, -0.40
90.0	5×5	5.0,15.0	-	-	0.59, -0.40	1.02, 0.37
90.0	7×7	5.0,15.0	-	-	0.38, -0.43	0.33, -0.79
90.0	10×10	5.0,15.0	-	-	0.61, -0.14	0.61, -0.31
90.0	15×15	5.0,15.0	-	-	0.09, -0.57	0.28, -0.42
90.0	20×20	5.0,15.0	-	-	0.32, -0.28	0.32, -0.13
90.0	30×30	5.0,15.0	-	-	0.92, 1.06	-0.87, 0.62

AGL, accelerated go live; SSD, source-to-surface distance; CCC, collapsed cone convolution; MC, Monte Carlo.

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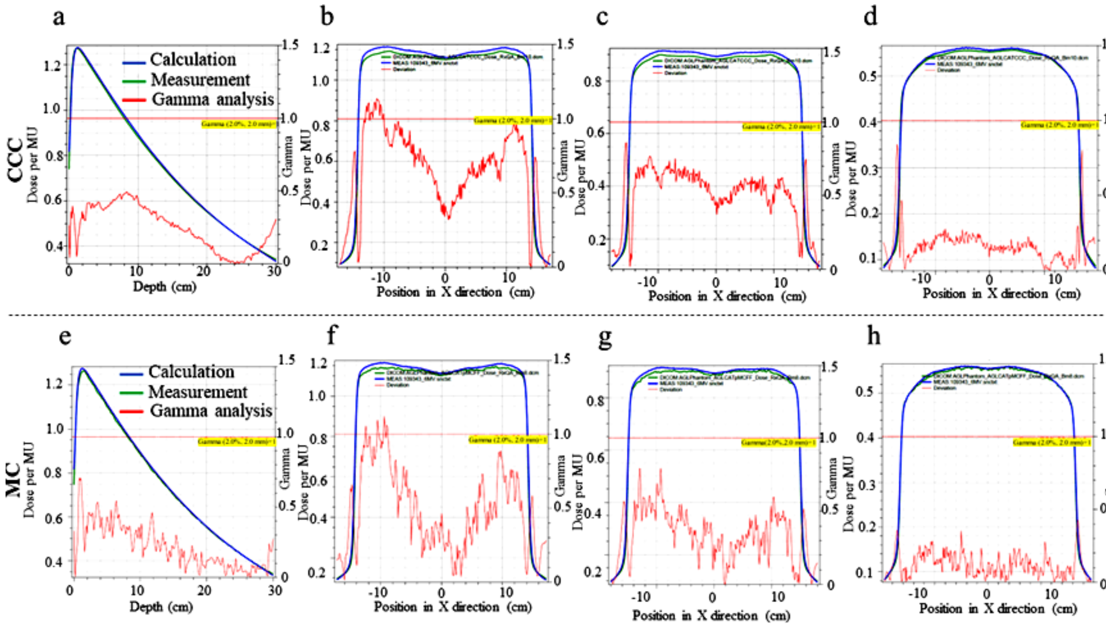

Figure 2. AGL of result of the PDD and OCR for 30×30 cm2 irradiation field size of 6 MV, **(a)** CCC, PDD, **(b)** CCC, OCR for depth of 5 cm, **(c)** CCC, OCR for depth of 10 cm, **(d)** CCC, OCR for depth of 15 cm, **(e)** MC, PDD, **(f)** MC, OCR for depth of 5 cm, **(g)** MC, OCR for depth of 10 cm, and **(h)** MC, OCR for depth of 15 cm.

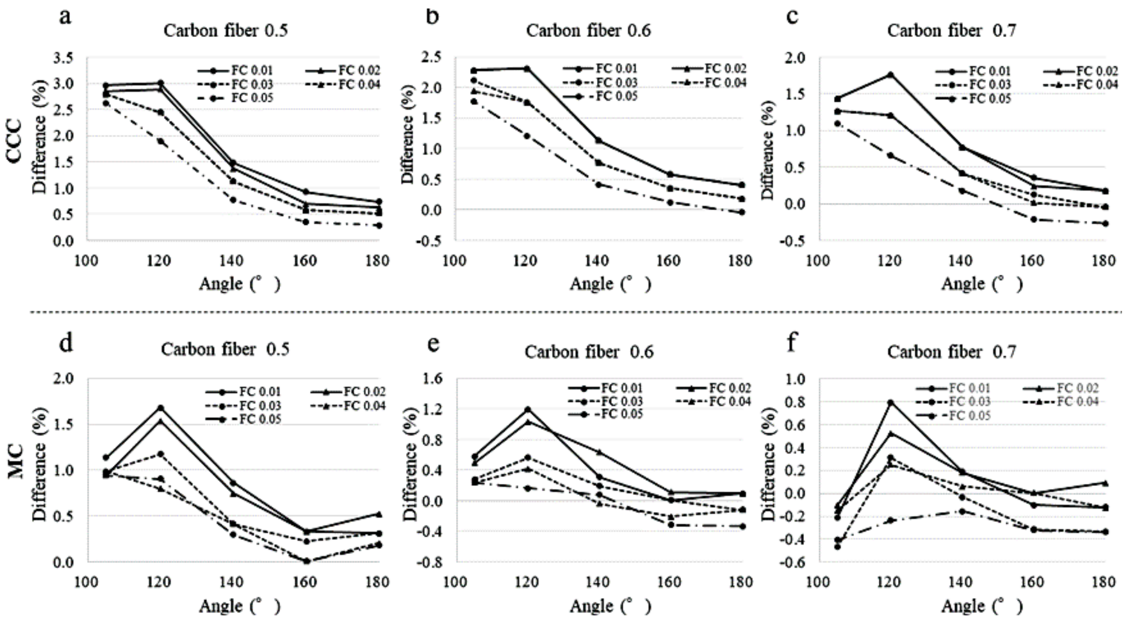

Figure 3. Relationship of dose difference between calculated and measured dose at 6 MV for couch modeling. **(a)** CCC, RED of carbon fiber: 0.5, **(b)** CCC, RED of carbon fiber: 0.6, **(c)** CCC, RED of carbon fiber: 0.7, **(d)** MC, RED of carbon fiber: 0.5, **(e)** MC, RED of carbon fiber: 0.6, and **(f)** MC, RED of carbon fiber: 0.7.

DISCUSSION

This study examined the safe and efficient start-up efforts for utilizing vendor commissioning support AGL. The commissioning period for AGL is 3 days, and as it is conducted simultaneously with the acceptance test, there are many measurement contents and time restrictions [4,15]. Consequently, we believe that the addition of measurement items by the user can lay the foundation for safe radiation therapy.

In this study, the user checked the position of the MLC and JAW considering the time required to adjust before AGL; consequently, the MLC and JAW positions were properly adjusted. The MLC and JAW position error affect the output dose and MLC parameters and thus must be evaluated [4,15]. Adjusting the MLC position can improve patient-specific quality assurance and avoid systematic errors for high-precision radiotherapy such as intensity-modulated radiotherapy (IMRT) and stereotactic radiotherapy [16].

In AGL, the benchmark test is validated only for a limited number of irradiation fields. There is a discrepancy greater than 1% in the two beams that do not reach the target value; however, the standard

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is satisfied within 2%. Further, the adjustment time is limited and therefore difficult to perfect. Moreover, the evaluation to be performed after AGL must be considered. The result of AGL exhibited no difference from that of the additional user measurement for irradiation fields larger than 3×3 using different types of chambers. The AGL was not measured for a small irradiation field size of < 2×2 cm^2. The difference between the measured and calculated dose was < 2% at CCC and 1% at MC. Herein, the tolerance level and dose difference varied in the calculation algorithm, and these characteristics should be understood before clinical practice [17-19]. Furthermore, IMRT and stereotactic radiotherapy often involves a small irradiation field, and it is important for the user to additionally evaluate small irradiation fields [20].

In CCC, for OCR of a 30-cm field size, there was a difference of > 1% in gamma analysis between the OCR profile shoulder shape and the central axial output dose for a gamma passing rate of 2%/2 mm > 1.0 and an output dose >1.0% for depths of 10 and 20 cm. The profile energy is correlated with the profile shoulder shape, and it is possible that adjusting the profile improved the dose difference that affects the beam quality in the depth direction [21,22].

The commissioning for output dose of attenuation of couch is an important factor in clinical initiation [13,22]. The RED was determined to be 0.6 with carbon fiber and 0.03 with foam, which was close to the values of 0.6 with carbon fiber and 0.05 with foam in a previous study [23]. Moreover, adjustments were made such that the overcorrection would not result in overdose. In addition, irradiation was rotated for output dose of attenuation of couch. Previous studies have reported that the absorption variation is dependent on the irradiation field size [24]. The rotating irradiation is useful for independently evaluating the detailed angles in advance, which facilitate the evaluation of three field irradiation sizes in a short time. In the application of LINACs, we consider that simple couch modeling techniques such as rotating irradiation can reduce the risk of operating errors without using special peripheral equipment.

The limitation of this study is that we could not examine the scanning parameters for CBCT within the facility at the time of commissioning [25]. Therefore, the radiation dose of CBCT was reduced with reference to the dose-efficient protocols of nearby facilities. The introduction of LINAC requires specific time constraints and experience, and we believe that it is more feasible to refer to nearby facilities and support from the community to realize a safer and more efficient introduction process.

CONCLUSION

This study of vendor commissioning support for LINAC aids users via extensive evaluations for output of LINAC and modeling of RTPS. Users can install equipment more safely by performing additional measurements and adjustments before and after the vendor commissioning support.

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