Chapter 6
Fixation

Shinsuke Yano

6.1 Fixation

Methods of stereotactic body irradiation and fixation have changed with the introduction of stereotactic body radiation therapy (SBRT). Compared to the brain, head, and neck cancer, it is difficult to target lesions with the body by stereotactic irradiation due to difficulty in achieving a stationary target. Lesions in the lung are particularly difficult to irradiate due to respiratory and other physiological movements. The method used for stereotactic body irradiation is set in each facility to maintain precise determination of tumor position [1–14]. The four-dimension computed tomography (CT) scan method was introduced in our facility, making use of the improved performance of CT compared to the free-breathing irradiation using dynamic tumor tracking method [9, 14–23].

This chapter discusses our clinical experience with this method focusing on (1) the requirements for the fixation device, (2) the characteristics of representative immobilization, (3) points that require attention for appropriate immobilization and setup, (4) fixation and setup error, (5) points that require attention regarding the dose at the time of immobilization, and (6) the interference of the fixation device with the gantry.

S. Yano (✉)
Division of Clinical Radiology Service, Kyoto University Hospital, 54 Shogoin-Kawaharacho, Sakyo-ku, Kyoto 606-8507, Japan
e-mail: yan@kuhp.kyoto-u.ac.jp

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6.2 Requirements of Immobilization for Patient Positioning

As stereotactic body irradiation requires a high degree of positional precision, a fixation device is used to increase precision and repeatability by maintaining the patient in the same position for the duration of the treatment. However, there may be a long delay between position verification and the start of irradiation, and this may increase patient discomfort, which in turn reduces positional precision. Therefore, it is necessary to keep the treatment time as short as possible.

In addition, the monitor units (MUs) needed in one irradiation port can become large, so a number of irradiation ports may be needed. This can result in a long treatment time of around 30 min, including verification with a large dose per fraction in stereotactic body irradiation. The requirements for patient positioning and fixation are as follows:

- Some degree of flexibility to allow the patient to maintain the position for a long time
- Ability to control the patient's movement during treatment
- Ability for the patient to repeatedly maintain the same position naturally
- Repeatability of placement on the bed for each treatment
- Hygienic and maximizes patient comfort

6.3 Types of Immobilization Device for Stereotactic Body Radiation Therapy

Various immobilization devices are available, each of which has advantages and disadvantages. It is necessary to choose the appropriate device for the therapeutic method used in each facility.

Various devices are available to control frame movement and precisely reproduce the patient's position, including a shell for body fixation, vacuum pillow-type fixation [24, 25] (Fig. 6.1), and a body frame [1–6, 16] (Fig. 6.2). Different systems make use of various methods to maximize accuracy, e.g., irradiation can be performed using a board [15, 16] to apply pressure to the abdomen for respiratory depression, with synchronized breathing control, dynamic tumor tracking irradiation [18–23] (Fig. 6.3), respiratory gating irradiation [8, 10, 11], or using an internal marker [23].

To confirm breathing position, we placed an infrared marker [21, 22] on the diaphragm region with an abdominal pressure belt and observed the breathing pattern using a spirometer [13]. Accurate and reproducible fixation could be achieved using this device.

Breathing-related movement can be controlled by suppressing diaphragmatic movement as with an abdominal pressure board. Whether movement is restrained can be determined by observing tumor movement by fluoroscopy, and the strength of pressure applied by the board can be regulated accordingly.

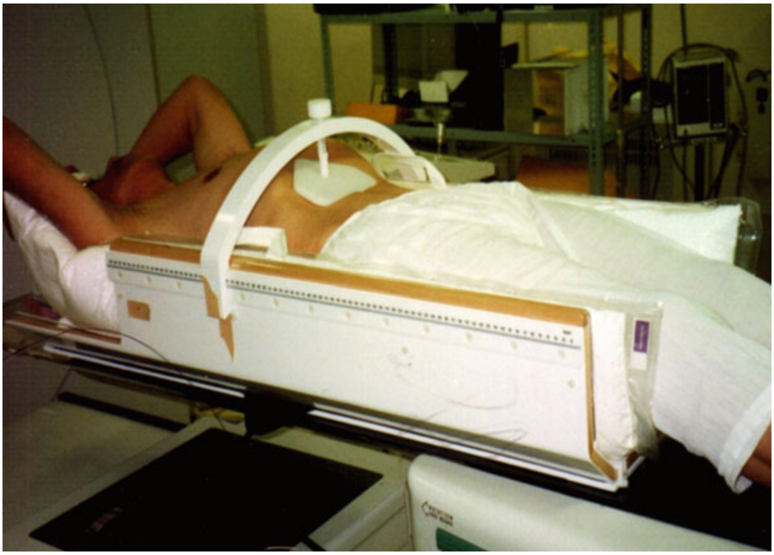

Fig. 6.1 Stereotactic body frame (Elekta): Patient setup using diaphragm control in SBRT. Breathing-related movement of tumor can be controlled

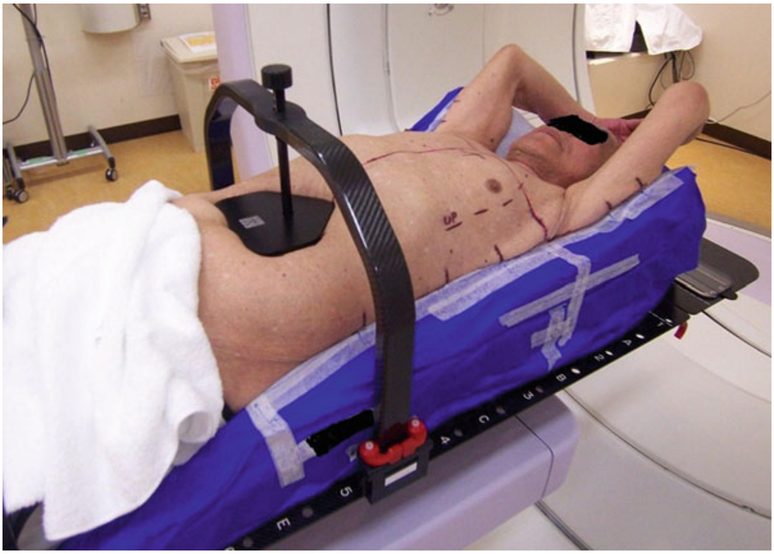

Fig. 6.2 Body FIX (Elekta): Patient setup using diaphragm control in SBRT

Fig. 6.3 Body FIX (Elekta): Patient setup in dynamic tracking irradiation. Positioning for dynamic tracking is setting in immobilization with free breathing condition, and the infrared marker is putting on upper abdomen for acquisition of breathing signal

In cases with a lesion in the lower lung field, diaphragm movement can be restrained by an average of more than 5 mm, and therefore the irradiation range can be minimized by reducing the movement of the tumor [15].

Depending on the case, breathing-related movement may be large when pressure is applied to the diaphragm region. Such movement may be controlled by applying abdominal pressure, but it may be necessary to apply oxygen inhalation as breathing tends to become relatively shallow with such treatment [7].

Then, I explain the function of the fixture with the change of the fixture of our facilities.

When we first began performing stereotactic body irradiation at our facilities during until 2007, we adopted the Stereotactic Body Frame (SBF) [1–6, 16] (Fig. 6.1) developed by the Swedish company Elekta with the cooperation of Karolinska Hospital in Stockholm.

We subsequently introduced the high-flexibility Body Fix [24, 25] (Fig. 6.3) for immobilization, which interfered little with the gantry and showed little dose absorption at our facilities.

Irradiation was carried out in patents under free-breathing conditions by dynamic tumor tracking irradiation [18–23]. It became clear that immobilization techniques with which it was easy to observe movement from each direction in fluoroscopy images were required.

This method is available for liver and pancreatic cancer, and clinical results have been reported for a therapeutic method using SBF adapted for body irradiation [1–6].

Figure 6.4 shows immobilization SBF for use in SBRT of the trunk region. The size and shape of SBF with a minimum opening of 550 mm are designed for

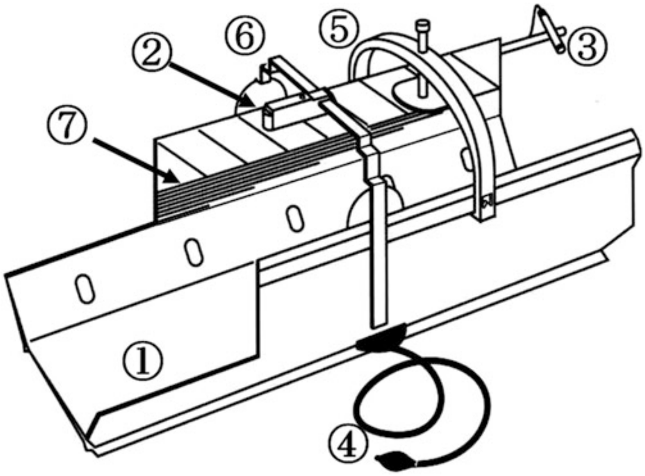

Fig. 6.4 Structure of SBF immobilization: (*1*) Body frame, (*2*) Chest marker, (*3*) Leg maker, (*4*) Level control, (*5*) Diaphragm control, (*6*) XY-axis scale, (*7*) localizer scale for CT image

CT, magnetic resonance (MR), and positron emission tomography (PET). The frame wall is composed of glass fiber and white birch plywood, low-density materials that keep attenuation of the beam to a minimum [16]. There is an atmospheric layer and a vacuum pillow inside the frame. CT level of pillow part is almost equivalent to atmosphere. This part can be molded along the body of the patient. Furthermore, a CT indicator made of polymethyl methacrylate (PMMA), which can read the three-dimensional coordinates on CT, is embedded within the inner wall of the frame, and a Z-axis scale made of plastic is attached to the outer wall. A XY- axis scale for positioning is shaped arch on a frame, and made of aluminum, which can remove during irradiation. There is a level control that made of rubber bag in unilateral of the frame base. This function can control to coordinate the position of horizontal direction with adjusting of air pressure. In addition, as other appliances, laser pointer can be set for skin marker on chest wall (Fig. 6.5a), and the pressure board can be set to control breathing movement on upper abdomen.

The stereotactic body frame (SBF) has many functions that were developed for stereotactic body radiation therapy (SBRT) with a high degree of reproducibility. We introduced Body Fix in place of SBF in our facilities in 2007 as it has a number of advantages in that it is composed of material with little dose absorption, its structure interferes little with the gantry, and it has high spatial flexibility. For dynamic tumor tracking irradiation, the patient is irradiated under free-breathing conditions. Therefore, a fixation device that facilitates observation of the movement of a marker and the lesion in fluoroscopy images during irradiation or verification was required. The fixation device requires precision, and a function to reproduce the setup position of bone exactly is required. Alignment requires use of a skin mark and an adjustment appliance prior to use. Bone position can be reproduced with greater precision and within a shorter time using image-guided radiation therapy

(IGRT) compared to previous methodologies. The position revision in verification enabled automatic reproduction of a position and a tilt with accurate six-axial (X, Y, Z, Roll, Pitch, and Yaw) revision of couch position. However, during setup, it is necessary to reproduce torsion and flexure of the body in a minimum requirement. Accordingly introduction of IGRT, the purpose of the fixture and the necessary matter changed. Use of a fixation device such as Body Fix, which is simple and shows little absorption, is effective for positioning verification using fluoroscopy, such as dynamic tracking irradiation or irradiation synchronized with respiration.

6.4 Points That Require Attention in Immobilization

Long-term patient fixation may be accompanied by patient discomfort, with reduced blood circulation resulting in numbness. In addition, low back pain due to remaining in the same posture for a long time may occur. To prevent these issues, it is necessary to fix the patient in as relaxed a state as possible. It is comfortable for patient that neck and both elbows are lifted up naturally in making immobilization. It is easier for patients to remain in the same position for a long time when they are relatively comfortable, and this improves precision.

For immobilization, we do not begin alignment immediately as it is important to confirm the patient's breathing and to perform the procedure with the patient in a relaxed state. This step must be performed manually in each case, and we explain the positioning procedure to the patient to secure his/her cooperation.

In the case of vacuum-type fixation, we should not be write mark and scan CT soon after making fixation. The patient is awakened after immobilization, and then the point of contact on the skin surface is marked to ensure application to the same position in each treatment (Fig. 6.5b). This can prevent extreme clamping and ensure that there are no differences in the conditions at the time of irradiation.

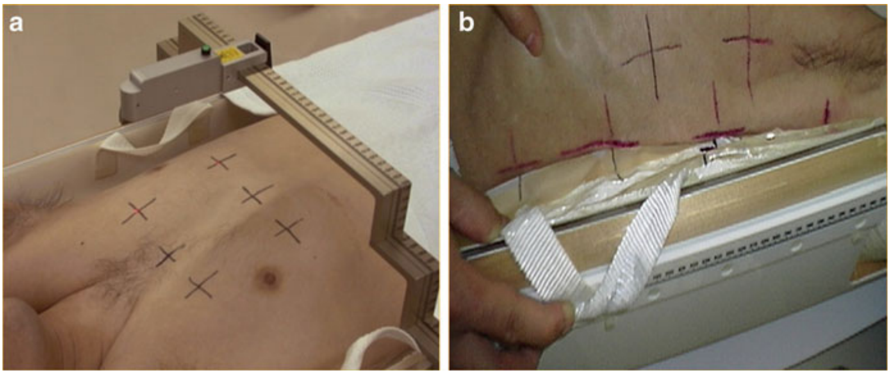

Fig. 6.5 (**a**): Skin marking line on contact point with immobilization is useful for setup in every positioning. (**b**): Chest laser marker on SBF. In positioning, this marker is used for setting to prevent of leaning and twisting body

With regard to the time to irradiate, it is desirable to set as possible the same time in consideration of time after a meal.

In the case of using diaphragm control and shell on chest, there is some possible of deteriorating in precision of setup position, and cause to pain of the patient.

6.5 Immobilization and Setup Error

Due to the high dose of radiation given at each time, repositioning accuracy may influence the radiation dose applied to the lesion.

Patient fixation is closely related to intra- and interfractional setup error. The positional precision depends on accurate repositioning and maintenance of the patient's position during irradiation. Positional precision is confirmed just before irradiation and any error is revised. It is necessary to maintain the position during treatment [26].

The introduction of IGRT technology has enabled bone position to be corrected just before irradiation, along with the position or tilt on X-ray images in six-axial directions, which can reduce the internal fractional setup error. However, we cannot revise the torsion of the body, curve, expansion, or contraction by IGRT revision. It leads to reducing internal fractional setup error to decrease these states by the setup using the fixture as much as possible. It is important that patient movement during irradiation remains within the bounds considered in intrafractional setup error, as outlined in the ICRU-62 report [27] regarding factors related to planning target volume (PTV).

It is important that the fixation device is capable of ensuring that the patient does not move during irradiation. Simultaneously, the fixation device must not be tight and uncomfortable to facilitate relaxation of the patient. If these conditions are satisfied, inter- and intra-fractional setup errors would be reduced, thus lowering the margin setting added to internal target volume (ITV).

Once immobilization has been achieved, adjoining regions of the skin are marked with lines (Fig. 6.5b). Lining up these marks on the right and left sides of the body can prevent rolling of the body axis.

When calvarial position accords in immobilization at the decided position, in the craniocaudal direction, the same position is reproduced every time. Therefore it is important to form the calvarial part of the fixture definitely.

The evaluation of repositioning is usually verified by bone position. For other methods, a tumor position is verified with higher precision by the observation of the internal marker using fluoroscopy or the verification of the organ using CBCT.

Agreement of tumor position according to the internal marker and CBCT increases the degree of positional precision, but changes in the trajectory of the irradiation beam and lesion depth affect the absorbed dose when there are changes in the body axis. Therefore, it is necessary to prevent changes in the body axis as much as possible because the fractional radiation dose is high.

Table 6.1 Setup accuracy using immobilization device for lung stereotactic body radiation therapy

Immobilization device	LAT (mm)	AP (mm)	SI (mm)	Reference
Body fix with dual vacuum	3.1 ± 2.6	3.4 ± 2.9	2.2 ± 1.9	Luo [28]
	2.9 ± 3.3	2.3 ± 2.5	3.2 ± 2.7	Fuss [29]
Body fix	-1.8 ± 3.2	0.3 ± 1.8	1.5 ± 3.7	Wang [30]
Stereotactic body frame	6	4	7	Negoro [15]
	3.3	3.4	4.4	Wulf [6]
	5	5	8	Lax [2]
	2.7 ± 2.3	2.5 ± 1.7	3.4 ± 2.7	Inga [31]
	0.11 ± 3.76	-2.44 ± 3.85	1.31 ± 5.84	Foster [32]
T-bar	3.7	5.1	5.1	Halperin [33]
Expanded form	5.3	3.6	5.4	Halperin [33]
Alpha cradle	2.0 ± 3.1	5.8 ± 1.4	2.9 ± 3.8	Inga [31]

For immobilization, it is necessary to achieve precise repositioning of the bone without leaning or twisting, and to ensure that the position can be maintained throughout treatment. The most suitable fixture choice is expected in consideration of an irradiation method, a collation method, irradiation time in each facility. I introduce the report about the setup error using various immobilization devices (Table. 6.1). An irradiation method and the collation methods are different in each report. For details, I suggest that you take each report into account.

6.6 Absorption Revision

In immobilization, it is necessary to achieve a structure in which there is little absorption or in which revision of absorption is possible, in addition to fixation of the body position. For revision of absorption in the treatment plan, it is necessary to use a device with the same geometry as that used in the planning stages at the time of irradiation. Therefore, for immobilization, it is desirable to fix the device to the same position of the couch at the time of irradiation as during the planning stage. We can reproduce the incident angle of the beam, couch passage distance, and couch absorption as in the treatment plan by appropriate geometric placement at the time of each irradiation dose.

Absorption revision varies according to the type of immobilization, material, and beam placement, and consists of the following:

1. Method to revise monitor unit (MU) value with the absorption factor of immobilization measured beforehand.
2. Method to calculate dose including immobilization to outer contour in the treatment plan.

Although it varies according to the type of immobilization, radiation dose may be reduced by more than 10 % due to absorption depending on the beam direction.

The clinical influence of the decrease in radiation dose associated with immobilization in each irradiation portal cannot be ignored, as it affects the total dose applied in treatment.

It is necessary to consider the precision of a radiation dose, such as changes in the surface dose produced by the size, thickness, and material of the immobilization device or attenuation of the radiation dose with immobilization in SBRT [34].

The following section presents data obtained with SBF, which was initially used at our facility.

6.6.1 Attenuation Rate of Radiation Dose Using an Immobilization Fixation Device

It is important to determine the dose attenuation of the fixation device in preparation for stereotactic body irradiation. The method for evaluation of dose attenuation involves use of a cylindrical phantom with a dose chamber in its center, set up inside the fixation device. We measured the dose attenuation at every gantry angle, and the attenuation rate was normalized relative to the dose in the direction without attenuation.

For example, Fig. 6.6a, b shows a graph of dose attenuation rate using SBF [16]. The rates increased from a gantry angle of 65° at which the beam began to overlap on SBF. Irradiation field completely overlap on SBF from a gantry angle of around 70° that showed more than 6 % of value.

At a gantry angle above 160°, the beam began to overlap to the prop of the couch. Then the radiation dose suddenly decreased on this gantry angle with dose attenuation of SBF and prop of the couch. In a real treatment plan, it is necessary to exclude the setting of beam placement for this part.

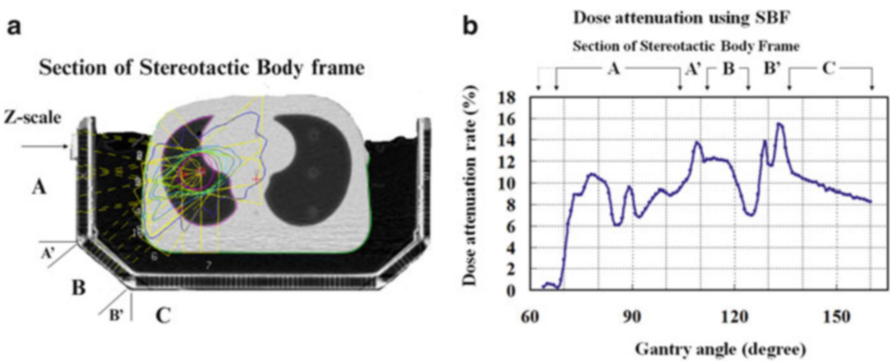

Fig. 6.6 (**a**): Section of SBF for correction of dose attenuation. Attenuation rate varies according to material and structure in immobilization. Section A: lateral panel, Section B: oblique panel, Section C: bottom panel. (**b**): Dose attenuation rate using SBF. As an example, this graph show measurement data of dose attenuation from a gantry angle of 65°–160° using phantom in SBF

Even if the attenuation rate of the radiation dose lies in the domain where the thickness of the frame is flat (A, B, C) (Fig. 6.6a), a change in dose is caused by influence of the internal structure at the incident angle to SBF. The relative decrease in radiation dose attenuation in Z-scale, which there is placed on corner rail of immobilization, was up to 15.4 % at a gantry angle of 133°.

The degree of dose attenuation varied between the sides, base, and angled part of the SBF, and the mean rate of the whole SBF was 9.3 %.

When a non-coplanar beam is used in stereotactic body irradiation, the incident direction of the beam for the fixation device is altered; the attenuation rate is also thought to change.

The dose attenuation rate with a couch angle of 20° increased of approximately 2.5 % compared with an angle of 0°, but the tendency was identical.

As the influence of dose attenuation in one fraction was considerable, it is necessary to revise the dose based on these data.

In preparation for stereotactic body irradiation, when the number of monitor units (MUs) is revised by manual calculations or automatically by the treatment planning device, it is important that corrected dose attenuation is confirmed the dose precision by dosimetry. It should be noted that dose attenuation can change markedly with slight changes in angle on dosimetry.

6.6.2 Influence on Clinical Target Dose in SBRT

Here, we present an example of the influence of dose attenuation on total fraction dose when attenuation of the fixation device occurs at the number portal among all of the irradiation portals in stereotactic body irradiation.

We evaluated the influence of the attenuation rate using SBF on a target dose of radioactivity in 21 clinical cases (Fig. 6.7) [16]. There was little influence on target dose when the SBF was set to a small number of incident irradiation portals relative to the total number of irradiation portals or when the attenuation dose of SBF was small. Without revision in each case, the target dose was decreased by an average of 5 %. In contrast, with a uniform revision value of 9.3 % of the radiation dose at each portal, the influence on target dose was reduced to approximately 1 %. As SBRT applies a large dose, the revision of absorption due to immobilization is an important factor affecting the precision of the radiation dose.

Stereotactic body irradiation is often carried out with multiple fixed portals and has dose attenuation of around 10 % of the fraction dose using fixation devices depending on the direction; this is a major problem in dose precision.

It is necessary to avoid the direction with large attenuation of the fixation device in setting the beam direction, or to revise dose attenuation of the fixation device. It is important to use appropriate materials for the fixation device to reduce the influence of absorption on dose attenuation.

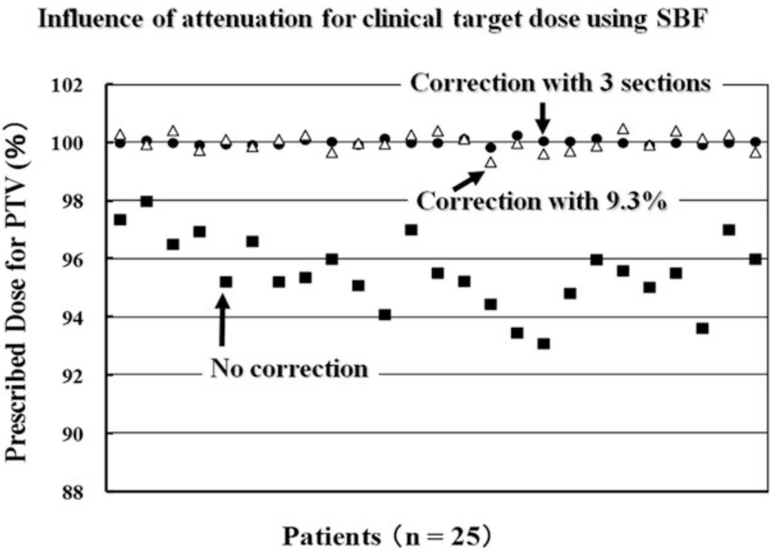

Fig. 6.7 Influence of attenuation for clinical target dose using SBF in SBRT. Correction with 3 sections (A, B, C section in Fig. 6.6a, b): perfectly revision for dose attenuation. Correction with 9.3 % (average of attenuation rate): revision almost possible for attenuation. No correction: target dose was decreased by an average 5 %

6.6.3 Changes in Surface Dose Associated with Immobilization

The influence of the administered dose varies according to the selected energy when using immobilization techniques. With immobilization, direct contact is made with the skin; therefore, the skin has a reduced protective effect compared to during procedures performed without a fixation device. When using absorption-type immobilization, it is necessary to establish a sufficient atmospheric layer around the body. We can expect re-build up phenomenal that target region is nearby.

The influence on skin absorption dose depends on field size, and a treatment plan to reduce the overlap of the beam on the skin side as much as possible is necessary.

It is important to measure the dose attenuation associated with immobilization, the change in skin dose by the structure used for immobilization, and its influence on target dose prior to the procedure. As an example of measurement data, the surface dose was 15.5 % without immobilization, but increased to 75.8 % using SBF, representing an increase in surface dose of 60.3 % for the peak dose [16].

This example shows that the increase in surface dose occurs suddenly with changes in material thickness. Therefore, it is necessary to pay close attention when choosing materials. The materials for a fixation device should be as firm as possible to avoid the outer wall part.

Materials of fixation device with atmospheric layers are desirable to utilize a skin protection effect with the re-build up of dose for a contact part to skin. As the effect when using an absorption-type fixation device fades if the atmospheric layer from the beam incidence direction is thin, it is necessary to maintain an atmospheric layer of ~5-cm thickness.

6.7 Evaluation of Interference by Immobilization

The planner can arrange the beam placement from various directions without limit in the treatment plan. In the treatment room, there are really many cases that cannot realize beam placement decided on treatment planning by a geometric limit.

When tumor position is shifted to right and left or ventral and dorsal side from midline of body, the couch shift from the center, and the height change. When the migration length is large from center, it is assumed that setting of gantry angle and couch angle is limited. When immobilization is used in a treatment plan, the ranges of gantry and couch angle are limited by the setting position against the couch changes. As a non-coplanar beam is often used in stereotactic body irradiation, it may be limited by the position of the immobilization device, particularly the position of the elbow. It is important to determine the movable range of the gantry and couch that can be used in the planning stage prior to commencing treatment. As an example, Fig. 6.8 shows the movable range of the couch and gantry with changes in the isocenter [16]. In this graph, the gantry angle and couch angle are plotted on

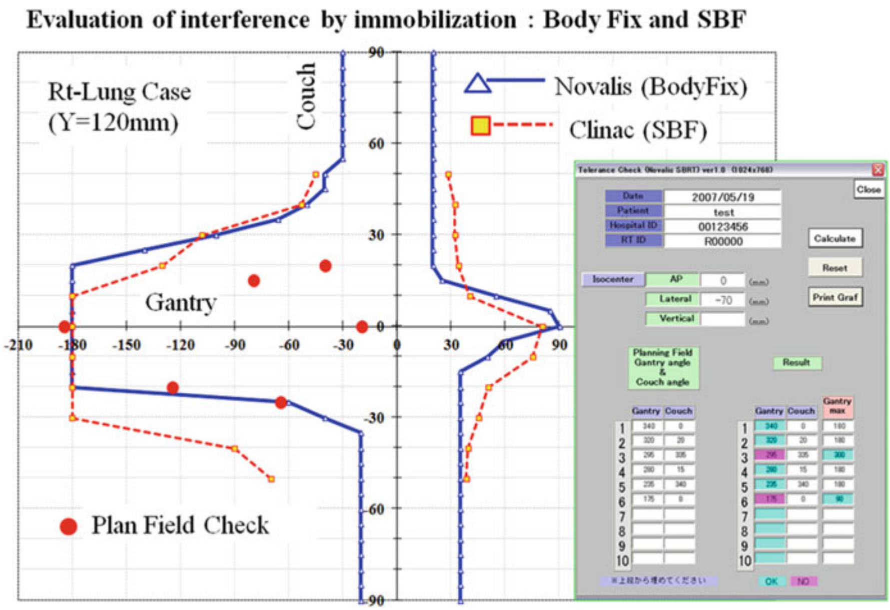

Fig. 6.8 Evaluation of interference by immobilization. Movable range of gantry and couch angle compare with Body Fix and SBF

the vertical axis and the horizontal axis, respectively. With regard to gantry rotation, right side of graph shows clockwise rotation of gantry and left side of graph shows counterclockwise rotation. For the couch angle, upper side of graph shows clockwise rotation from 0°, lower side of graph shows counterclockwise rotation from 0°. With regard to the angle of the gantry and couch, the range of surrounded area indicate the possible range of the setting. This range change condition by isocenter position per patient.

The interference range changes for each device, combination of immobilization, and lesion position. We can set the beam placement without re-planning by plotting the interference range beforehand. Effective and safe treatment can be achieved through irradiation based on a careful treatment plan.

This chapter presents the requirements for fixation, characteristics, and points that require attention for use. As the irradiation methods are different, the most suitable fixation device at each facility is selected in accordance with its purpose.

In addition, fixation devices will in future evolve to support new techniques, such as IGRT, dynamic tracking irradiation, and synchronized breathing control irradiation.

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