A gamma-ray therapeutic system applied to treatment of body tumors

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Abstract In order to treat malignant tumors in human body, a stereotactic gamma-ray whole-body therapeutic system has been developed. This system is a typical large mechatronics treatment machine. In this paper, its main working principles and characteristics are introduced. This system comprises a special gallows frame with an open vertical structure, a changeable collimator device by which the size of convergence center can be chosen, and a 3D treatment couch. A computer brings the couch to target position automatically. Therefore precise and dynamic rotary converging therapy for tumors located anywhere in the body has been realized. The system's performance has been proved in practice, which includes good curative effect, reliable automation, and safe and secure operation.

Keywords Gamma knife, Whole-body therapy, Rotary converging, Radiation therapy, Intensity modulation

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1 Introduction

Stereotactic converging therapy using gamma rays generated by cobalt-60 (^{60}Co) sources is an effective method to treat malignant tumors, with curative effect and a low degree of normal tissue damage. In late 1980s, Elekta Instruments, A.B. (Stockholm, Sweden), developed the Leksell gamma knife that applied statically converging method to stereotactical treatment for tumors in brain.[1, 2] In this system, 201 beams of gamma ray focus at a convergence center statically. This focus with high dose irradiates the target volume, and normal tissues receive less dose and therefore less damage at the same time.

In the middle of 1990s, an improved gamma knife applied to treatment for brain tumors that realized dynamical rotary converging therapy was developed in China. This gamma knife is named "The OUR Rotating Gamma System" (RGS). The principle of "the gamma rays rotary converging element" (Chinese Patent Number: ZL 961 7370.X) has been applied to RGS.[3] It uses 30 cobalt-60 (^{60}Co) sources distributed over a hemispherical source-body to treat brain tumors stereotactically. When the source body rotates during treatment, 30 gamma ray beams form 30 conical spheres of non-equal conic top angle and converge at a focus. Consequently the degree of normal tissue damage is decreased and the curative effect is improved.

The above gamma knives can only be applied to the treatment for brain tumors due to the design constraints of the mechanism. In order to apply dynamical rotary converging therapy to body tumors and extend the therapeutic range of the gamma knife from head to whole body, we developed a stereotactic gamma ray whole-body therapeutic system (the Whole-body Gamma Knife System, WGS) in 1998, with the incorporation of Shenzhen OUR International Technology & Science CO., LTD. This system is a typical large mechatronics treatment machine.

2 Structure and method

2.1 Main machine

The WGS consists of the main machine and the electro-control system. The main machine is composed of radiation collimating system, gantry, and 3D treatment couch and stereotactic location system (Fig.1).

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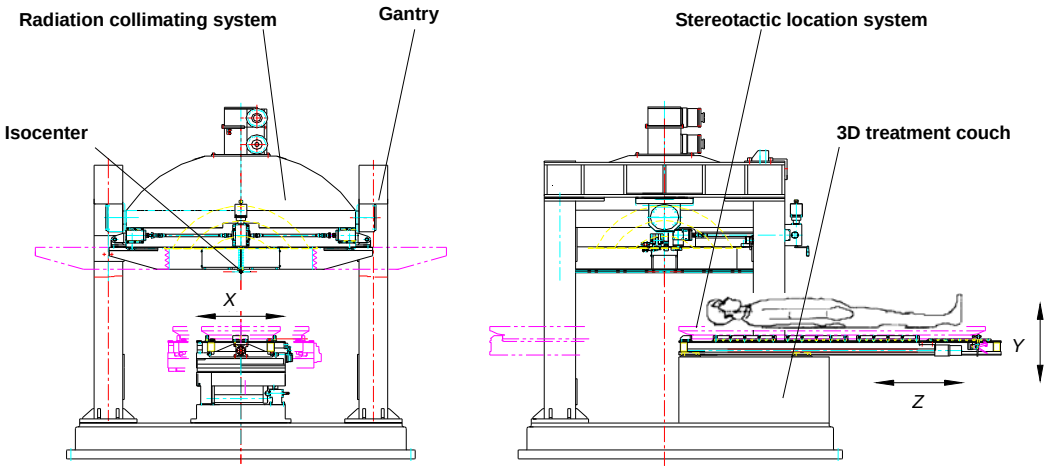

Fig.1 The main machine.

2.1.1 Radiation collimating system

The radiation collimating system consists of the source body, cobalt-60 (^{60}Co) sources, collimating body, shielding body, driving mechanism, shielding doors, and shielding bars. It provides the following functions: shielding radioactive sources, changing collimator and rotary converging irradiation (Fig.2). There are 4 groups of holes distributed over the collimating body. Each group comprises 30 holes. Three of them are used as collimators respectively with nominal diameters of 3, 12, and 18 mm, through which focuses with different size can be chosen. The shielding bars are mounted in the last group holes that are used to block gamma-ray beams in non-treatment condition. There are 30 cobalt-60 (^{60}Co) sealed radioactive sources distributed over the source body, with the focal dose rate of 3 Gy/min (initially loaded). During the treatment course, the collimating body initially rotates $N\times 90^\circ$ relative to the source body (N is equal to 1,2 or 3), according to the chosen collimator and diameter of beams. Then the collimating body and the source body rotate synchronously at rotational speeds of 1~6 revolutions per minutes and 30 beams of gamma ray focus at the isocenter to treat tumors. The distance between the isocenter and ^{60}Co sources is 425 mm. After treatment, the collimating body rotates to its original position and shielding bars block the gamma-ray beams. The shielding body, shielding doors and shielding bars constitute a double-shielding enclosure weighting nearly 12,000 kg to ensure a safe working environment under the circumstances of non-therapeutic running.

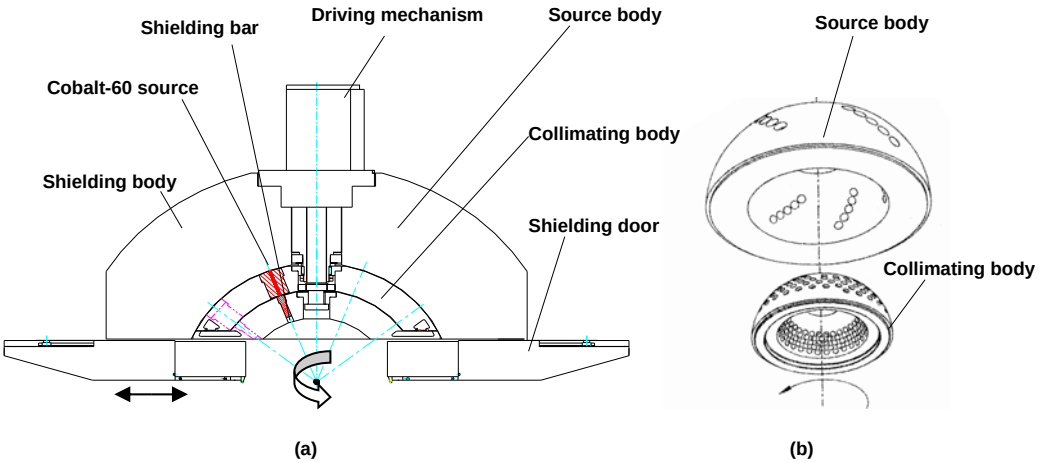

Fig.2 The radiation collimating system.

The radiation collimating system is mounted on the gantry that has an open vertical structure with a special gallows frame, thereby allowing the whole-body therapy.

2.1.2 3D treatment couch

The 3D treatment couch is mounted under the gallows frame. It can move respectively in the direction of *X*-axis, *Y*-axis, and *Z*-axis. Each axis is driven by the step-servo motor under the control of computer. The couch is also fitted with a set of manually-operated emergency mechanism. Once contingency such as power failure, etc. occurs, an operator can manually lower the patient on the couch down to safe level quickly.

The system is capable of treating relatively large tumors. On treatment, a tumor to be treated is divided into several target volumes. The couch moves under the control of computer and locates a single target volume on the position of isocenter. Then 30 gamma ray beams converge at an isocenter and irradiate the target. All target volumes are treated one by one such that the entire tumor volume has been enveloped.

With the incorporation of a treatment planning system (TPS), the treatment couch can move in 3 directions (*X*, *Y* and *Z*) simultaneously and tumors can be scanned by the machine focus stereotactically.

2.1.3 Stereotactic location system

The stereotactic location system is mounted on the treatment couch. It comprises a negative pressure couch and a special frame that can be mounted on the 3D treatment couch. It is applied to orienting the position of target and establishing patient coordinates to determine the position of the target relative to isocenter.

2.2 Electro-control system

The electro-control system is composed of the control console, electro-control panel, power system and electro-control software. It is used to control the motion of the 3D treatment couch, source body, collimating body, and shielding doors. Additionally, it implements treatment data input, treatment situation monitoring and other functions. The diagram of control system is shown in Fig.3.

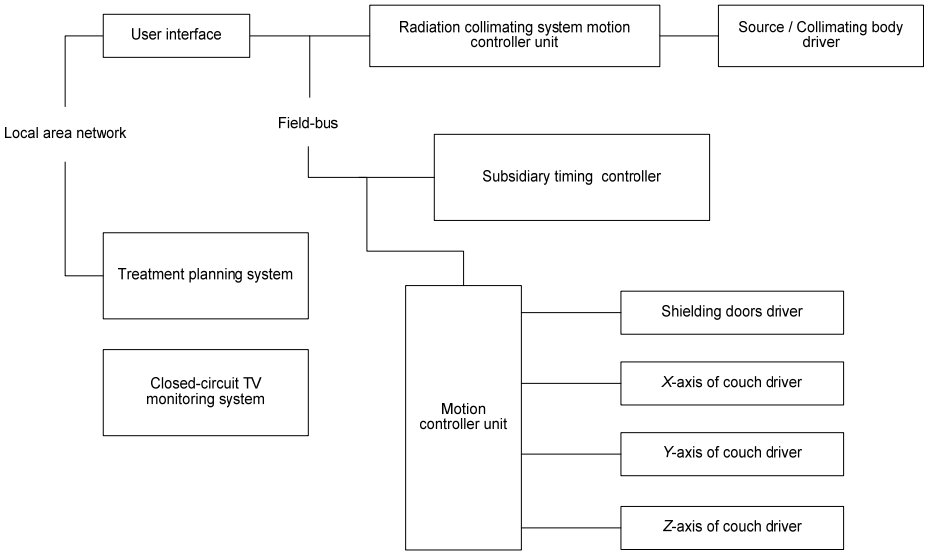

Fig.3 The diagram of control system.

3 Results

The technical specifications of the WGS are listed in Table 1. The WGS has similar physical characteristics to RGS because of its collimating structure and converging principle. Goetsgh *et al*. and YAO Jing-Zhang *et al*. have researched physical characteristics of the rotating converging gamma knife.[4, 5] The results demonstrate that gamma knives using the rotating converging principle have higher dose ratio on focus and other advantages, and are suitable for radiation therapy.

Table 1 Technical specification of the WGS

Items	Parameters
Total size (length×width×height)	3050mm×2250mm×2580mm
Total weight	About 14000 kg
Number of sources	30
Focus dose rate	3 Gy/min (in water)
Collimator size	3 types
Accuracy of isocenter	0.5 mm
Maximum load of treatment couch	135 kg
Treatment couch range (X×Y×Z)	780mm×450 mm×1320mm

The WGS is suitable for the treatment of tumors located anywhere within human body. Its main indications include: primary and metastatic lung carcinomata; primary and metastatic hepatocarcinomata; esophageal and mediastinal cancers; lymphogenous metastases of malignancies derived from pulmonary hilar, mediastinum, abdominal cavity and pelvic cavity; adenocarcinoma of the pancreas, carcinoma of the gallbladder and cancer of the biliary duct; carcinoma of the urinary bladder and prostatic cancer; and gynecological tumors.[6]

The WGS has high mechanical position accuracy as being described in the enterprise standard of Shenzhen OUR International Technology & Science CO., LTD. Its convergence error is less than 0.3mm.The inaccuracy brought about by the rotating of scanning mechanisms is less than 0.1 mm. Its localization error is less than 0.1 mm.Total mechanical error is less than 0.5 mm**.**

The WGS is claimed by the manufacturer to shield irradiation well and have sufficient security. In June 1998, the capability of radiation protection of the first WGS was evaluated by the Shandong Sanitation and Epidemic Prevention Center, China. The lower radiation leakage was measured by using portable X-γ ray dosimeters and the higher leakage was measured by using thermoluminescent units distributed at tens of locations near the WGS. The results show that the leakage dose at 1 meter from the surface of the WGS is 0.50-1.10 μGy per hour during no-treatment period. And under treatment the leakage dose is 0.14-2.00 μGy per hour at exterior of the WGS such as console, crush-room, waiting room, etc..

In December 1999, the WGS has been given the manufacture approval by the Medical Devices and Apparatus of State Pharmaceutical Administration, the production in batches has commenced.

4 Discussions

The gamma knife has distinct advantages compared with large beam field treatment machines, such as high dose ratio of target and less damage of normal tissues. However, the conventional gamma knife can only be applied to the treatment of brain tumors. In order to adapt the characteristics of body tumors with larger size and distributing extent, new mechanic structure and control method have been used in the WGS.

In sharp contrast to the head gamma knife with its horizontal structure,[7, 8] the WGS has an open vertical structure with a special gallows frame. Furthermore, the range of the 3D treatment couch is large: 780 mm × 450 mm × 1320 mm ($X \times Y \times Z$). Consequently, treatment volume is extended and treatment for tumors throughout the body is possible.

When rotary irradiation treatment is carried out by a linac, its gantry must rotate around the couch. Due to the weight of the treatment head, the focus position tends to shift and the treatment accuracy is degraded.[9, 10] The WGS can complete a rotary converging treatment without the gantry rotating. It has good rigidity and high mechanical accuracy.

In the WGS, the sealed ^{60}Co source package is made up of double-layer stainless steel vessel. It acts as additional shielding together with the shielding bars, shielding doors and shielding body. Linked mechanisms are applied in every moving device to ensure patient safety.

The 3D treatment couch can move in three directions (X, Y and Z) independently or simultaneously, being controlled by computer. It is applied to automatically localize the target precisely and to provide automatic multi-focus therapy. With the implementation of a treatment planning system, IMRT can be car-

ried out by the WGS.

The dynamic rotary converging therapy method is applied in the WGS. In sharp contrast to static converging therapy, gamma rays do not follow fixed paths to penetrate the tissues around the target. Therefore, the irradiation dose absorbed by normal tissues becomes more uniform and dispersive, resulting in a better curative effect. At the same time, the number of sources decreases and the source body's structure is simplified compared to the Leksell gamma knife.

The WGS uses a changeable collimator. Depending upon the treatment requirements, any of three different focus sites can be chosen. Treatment is improved, and treatment volume can be expended.

5 Conclusions

Because of its new mechanical structure and control methods, the WGS is the first gamma knife to be applied to treating tumors located anywhere within human body. It has the ability to rotate, dynamically converge gamma rays, change size of focus, and locate the target automatically during treatment. Its good performance has been proved in practice, which includes better curative effect, greater automatic range and improved safety. With the implementation of a treatment planning system, IMRT can be carried out by the WGS.

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