PHOTON TREATMENT SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application No. 63/571.589 filed March 29, 2024. which is incorporated by reference herein in its entirety.

FIELD

Provided herein is technology relating to treating disease and particularly, but not exclusively, to systems and methods for treating a patient in an upright position with photon radiation.

BACKGROUND

Treatment of cancer often involves exposing tumors to photon radiation to kill cancer cells. Conventional radiotherapy is delivered to a patient with the patient in a horizontal (e.g., supine or prone) position, in part because treatment planning uses diagnostic imaging data acquired with patients positioned in a horizontal position. However, improvements in cancer treatment are provided by treating patients in an upright position. See, e.g., Rahim (2020) "Upright radiation therapy – A historical reflection and opportunities for future applications" Frontiers in Oncology 10: 213, incorporated herein by reference. See also Boisbouvier (2022) "Upright patient positioning for pelvic radiotherapy treatments" Technical Innovations & Patient Support in Radiation Oncology 24: 124–130. While upright radiotherapy provides benefits with respect to patient comfort and improved treatment outcomes, technologies for imaging and treating patients in an upright position are underdeveloped. Accordingly, new upright radiotherapy and imaging technologies are needed for treating patients in an upright position.

SUMMARY

Accordingly, provided herein is technology relating to treating a patient having a disease and particularly, but not exclusively, to systems and methods for treating a cancer patient in an upright position (e.g., standing, tilted, sitting, kneeling, or perched) with photon radiation. Systems comprise a patient rotation system, a medical imaging system, and a beam delivery system. In some embodiments, medical diagnostic images provided by the medical imaging system of the patient in an upright position are used to

plan radiological treatment of the patient in an upright position using a photon beam generated by the beam delivery system. In some embodiments, medical diagnostic images provided by the medical imaging system of the patient in an upright position are also used to verify the position of the patient prior to treatment of the patient in an upright position using a photon beam generated by the beam delivery system. In some embodiments, medical diagnostic images provided by the medical imaging system of the patient in an upright position are used to adjust the position of the patient prior to treatment.

In some embodiments, the patient rotation system stabilizes and supports a patent in an upright position, and both the process of medical imaging and the process of radiological treatment are performed using the same patient rotation system to support and position the patient in the same position. Imaging and/or treating patients in an upright position provides the benefits of increasing patient comfort and improving patient stability with respect to conventional technologies. Further, diagnosis and/or treatment of patients in an upright position provides advantages over conventional diagnosis and/or treatment of patients in a horizontal position for many indications (e.g., lung cancer, breast cancer).

Accordingly, embodiments of the technology provide a photon beam delivery system for use in a photon radiation treatment system. For example, in some embodiments, the photon beam delivery system comprises a photon generator configured to produce a photon beam (e.g., a beam of high-energy photons (e.g., an x-ray beam)); a collimator positioned between the photon generator and a patient; a collimator housing positioned around the collimator, wherein the collimator is coupled to the collimator housing using an interference fit; and a multileaf collimator positioned between the collimator and the patient; wherein, the photon beam passes through the collimator and multileaf collimator before reaching the patient. In some embodiments, the photon generator includes a waveguide and a waveguide shield positioned around the waveguide. In some embodiments, the waveguide shield is coupled to a rail configured to allow the waveguide shield to move between a first position and a second position, wherein the waveguide shield is positioned around the waveguide in the first position and the waveguide shield is positioned at a distance away from the waveguide in the second position.

In some embodiments, the beam delivery system further comprises an adjustment ring coupled to the photon generator; and a mounting plate abutting the adjustment ring, wherein the adjustment ring and mounting plate are configured to

adjust the orientation of the photon generator relative to the collimator. In some embodiments, the adjustment ring and mounting plate make contact along a substantially spherical surface.

In some embodiments, the beam delivery system comprises a nozzle housing comprising an indentation, wherein the indentation is sized and configured to prevent collision of the beam delivery system, the patient, and the photon radiation treatment system during operation. In some embodiments, the beam delivery system is configured to move between a treatment position and a storage position. In some embodiments, the beam delivery system further comprises a shutter, wherein the shutter is configured to be in a lowered position when the beam delivery system is in the treatment position and the shutter is configured to be in a raised position when the beam delivery system is in the storage position. In some embodiments, the beam delivery system comprises a nozzle configured to move between a treatment position and a storage position. In some embodiments, the beam delivery system further comprises a shutter, wherein the shutter is configured to be in a lowered position when the nozzle is in the treatment position and the shutter is configured to be in a raised position when the nozzle is in the storage position.

In some embodiments, the multileaf collimator is configured to rotate around a beam axis alternately between a first position and a second position while the beam delivery system provides the beam of high-energy photons. In some embodiments, the multileaf collimator rotates approximately 5 to 45 degrees (e.g., 5, 10, 15, 20, 25, 30, 35, 40, or 45 degrees) between the first position and the second position. In some embodiments, the multileaf collimator rotates approximately 5 to 25 degrees (e.g., 5, 10, 15, 20, or 25 degrees) to the first position or to the second position. In some embodiments, the multileaf collimator rotates approximately 30 degrees (e.g., 25.0, 25.5, 26.0, 26.5, 27.0, 27.5, 28.0, 28.5, 29.0, 29.5, 30.0, 30.5, 31.0, 31.5, 32.0, 32.5, 33.0, 33.5, 34.0, 34.5, or 35.0 degrees) between the first position and the second position. In some embodiments, the multileaf collimator rotates approximately 15 degrees (e.g., 12.0, 12.5, 13.0, 13.5, 14.0, 14.5, 15.0, 15.5, 16.0, 16.5, 17.0, 17.5, or 18.0 degrees) to the first position or to the second position.

In some embodiments, the multileaf collimator rotates between the first position and the second position while a patient is rotated around a patient axis of rotation. In some embodiments, the multileaf collimator rotates between the first position and the second position while a number of leaves of the multileaf collimator are translated.

Further, the technology provides embodiments of a photon radiation treatment system. For example, in some embodiments, a photon radiation treatment system comprises a beam delivery system, a medical imaging system, and a patient rotation system. In some embodiments, the beam delivery system comprises a photon generator configured to produce a photon beam (e.g., a beam of high-energy photons (e.g., an x-ray beam)); a collimator positioned between the photon generator and a patient; a collimator housing positioned around the collimator, wherein the collimator is coupled to the collimator housing using an interference fit; and a multileaf collimator positioned between the collimator and the patient; wherein, the photon beam passes through the collimator and multileaf collimator before reaching the patient. In some embodiments, the medical imaging system comprises a scanner ring configured to move between an overhead position and an imaging position, and wherein the beam delivery system is configured to move between a treatment position and a storage position. In some embodiments, the scanner ring is in the overhead position when the beam delivery system is in the treatment position and the scanner ring is in the imaging position when the beam delivery system is in the storage position. In some embodiments, movement of the scanner ring between the overhead position and the imaging position is coordinated with movement of the beam delivery system between the treatment position and the storage position. In some embodiments, the patient rotation system is configured to support a patient in an upright position for imaging and treatment.

In some embodiments, the medical imaging system comprises a first scanner pillar and a second scanner pillar; a gantry rotatably coupled to the first scanner pillar and the second scanner pillar; and a scanner ring translatably coupled to the gantry, wherein the scanner ring comprises a photon source and a photon detector on opposite sides of a bore surrounded by the scanner ring. In some embodiments, the patient rotation system is configured to support a patient in a tilted position. In some embodiments, the photon radiation treatment system further comprises a patient supported in a tilted position. In some embodiments, the gantry is rotated around a horizontal axis for imaging the patient in a tilted position. In some embodiments, the patient supported in a tilted position is contacted with photon radiation produced by the beam generation system. In some embodiments, the medical imaging system is provided in a rotated orientation such that an angle of approximately 110 to 135 degrees is formed between the beam axis and the major axis of the scanner bridge. In some embodiments, the rotated orientation of the medical imaging system provides an

increased ingress/egress area relative to the medical imaging system in an unrotated orientation.

In some embodiments, the technology provides method of treating a patient. In some method embodiments described herein, the patient has a disease in need of treatment, e.g., a cancer in need of treatment. For example, in some embodiments, methods comprise providing a photon radiation treatment system comprising a beam delivery system, a medical imaging system, and a patient rotation system; positioning a patient on the patient rotation system in an upright position; imaging the patent on the patient rotation system in the upright position; producing a photon beam by the beam delivery system; and contacting the patient in the upright position with the photon beam. In some embodiments, methods further comprise rotating the patient rotation system and the patient while contacting the patient with the photon beam. In some embodiments, methods further comprise rotating a multileaf collimator around a beam axis alternately between a first position and a second position while contacting the patient with the photon beam. In some embodiments, the first position and the second position are approximately 5 to 45 degrees (e.g., 5, 10, 15, 20, 25, 30, 35, 40, or 45 degrees) apart. In some embodiments, the first position and the second position are approximately 30 degrees (e.g., 25.0, 25.5, 26.0, 26.5, 27.0, 27.5, 28.0, 28.5, 29.0, 29.5, 30.0, 30.5, 31.0, 31.5, 32.0, 32.5, 33.0, 33.5, 34.0, 34.5, or 35.0 degrees) apart. In some embodiments, methods further comprise translating the patient in a vertical direction while contacting the patient with the photon beam. In some embodiments, methods further comprise translating a number of leaves of a multileaf collimator while contacting the patient with the photon beam. In some embodiments, upright position of the patient is a tilted position locating the patient head posteriorly and the patient feet anteriorly.

In some embodiments, methods comprise providing a photon radiation treatment system comprising a beam delivery system, a medical imaging system, and a patient rotation system; positioning a patient on the patient rotation system in an upright position; imaging the patent on the patient rotation system in an upright position; producing a photon beam by the beam delivery system; and contacting the patient in the upright position with the photon beam while simultaneously rotating the patient rotation system and the patient; rotating a multileaf collimator around a beam axis alternately between a first position and a second position; translating the patient in a vertical direction; and translating a number of leaves of a multileaf collimator. In some embodiments, the first position and the second position are approximately 5 to 45

degrees (e.g., 5, 10, 15, 20, 25, 30, 35, 40, or 45 degrees) apart. In some embodiments, the first position and the second position are approximately 30 degrees (e.g., 25.0, 25.5, 26.0, 26.5, 27.0, 27.5, 28.0, 28.5, 29.0, 29.5, 30.0, 30.5, 31.0, 31.5, 32.0, 32.5, 33.0, 33.5, 34.0, 34.5, or 35.0 degrees) apart. In some embodiments, imaging the patient provides medical images of the patient for planning treatment, verifying patient position, or adjusting patient position. In some embodiments, the patient has a cancer.

In some embodiments, methods comprise providing a medical imaging system comprising a scanner ring in an overhead position; providing a beam delivery system in a storage position; positioning a patient on a patient rotation system in an upright position; translating the scanner ring to an imaging position in which the patient is located within a bore of the scanner ring; imaging the patient; translating the scanner ring to the overhead position; translating the beam delivery system to a treatment position; contacting the patient with a photon beam produced by the beam delivery system; and translating the beam delivery system to the storage position. In some embodiments, methods further comprise rotating the patient rotation system and the patient while contacting the patient with the photon beam. In some embodiments, imaging the patient provides medical images of the patient for planning treatment, verifying patient position, or adjusting patient position. In some embodiments, the patient has a cancer. In some embodiments, the beam delivery system comprises a nozzle housing and the nozzle housing comprises an indentation to provide clearance for rotation of the patient rotation system and/or the patient when the beam delivery system is in the treatment position. In some embodiments, the beam delivery system in the storage position provides the nozzle housing in a position that locates a surface of the nozzle housing to be flush with a wall. In some embodiments, the beam delivery system further comprises a shutter that covers a void in the wall when the beam delivery system is in the storage position.

In some embodiments, methods comprise providing a photon radiation treatment system comprising a beam delivery system and a patient rotation system; positioning a patient on the patient rotation system in a tilted position, wherein the patient comprises a head and feet; and contacting the patient with photon radiation produced by the beam delivery system while the patient is in the tilted position. In some embodiments, positioning a patient on the patient rotation system in a tilted position comprises positioning the patient in an upright position on the patient rotation system and rotating the patient rotation system and the patient around a horizontal axis so that the head of the patient moves posteriorly, and the feet of the patient move anteriorly. In

some embodiments, the patient in the tilted position is tilted approximately 15 degrees (e.g., 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, or 20 degrees) with respect to a Z axis.

Some portions of this description describe the embodiments of the technology in terms of algorithms and symbolic representations of operations on information. These algorithmic descriptions and representations are commonly used by those skilled in the data processing arts to convey the substance of their work effectively to others skilled in the art. These operations, while described functionally, computationally, or logically, are understood to be implemented by computer programs or equivalent electrical circuits, microcode, or the like. Furthermore, it has also proven convenient at times to refer to these arrangements of operations as modules, without loss of generality. The described operations and their associated modules may be embodied in software, firmware, hardware, or any combinations thereof.

Certain steps, operations, or processes described herein may be performed or implemented with one or more hardware or software modules, alone or in combination with other devices. In some embodiments, a software module is implemented with a computer program product comprising a computer-readable medium containing computer program code, which can be executed by a computer processor for performing any or all steps, operations, or processes described.

In some embodiments, systems comprise a computer and/or data storage provided virtually (e.g., as a cloud computing resource). In particular embodiments, the technology comprises use of cloud computing to provide a virtual computer system that comprises the components and/or performs the functions of a computer as described herein. Thus, in some embodiments, cloud computing provides infrastructure, applications, and software as described herein through a network and/or over the internet. In some embodiments, computing resources (e.g., data analysis, calculation, data storage, application programs, file storage, etc.) are remotely provided over a network (e.g., the internet; and/or a cellular network).

Embodiments of the technology may also relate to an apparatus for performing the operations herein. This apparatus may be specially constructed for the required purposes (e.g., an application-specific integrated circuit or a field-programmable gate array) and/or it may comprise a general-purpose computing device (e.g., a microcontroller, microprocessor, and the like) selectively activated or reconfigured by a computer program stored in the computer. The apparatus may be configured to perform one or more steps, actions, and/or functions described herein, e.g., provided as instructions of a computer program. Such a computer program may be stored in a non-

transitory, tangible computer readable storage medium or any type of media suitable for storing electronic instructions, which may be coupled to a computer system bus. Furthermore, any computing systems referred to in the specification may include a single processor or may be architectures employing multiple processor designs for increased computing capability.

Additional embodiments will be apparent to persons skilled in the relevant art based on the teachings contained herein.

BRIEF DESCRIPTION OF THE DRAWINGS

The patent or application file contains at least one drawing executed in color. Copies of this patent or patent application publication with color drawing(s) will be provided by the Office upon request and payment of the necessary fee.

These and other features, aspects, and advantages of the present technology will become better understood with regard to the following drawings.

FIG. 1 is a schematic drawing showing an orthographic view a treatment room. FIG. 1 shows a radiation beam (800) produced by a source (100) and an axis of rotation (700) of the patient. The isocenter (900) is shown at the intersection of the radiation beam (800) and the axis of rotation (700) of the patient. FIG. 1 shows a coordinate system used herein that is established relative to the source (100), radiation beam (800), and axis of rotation (700). The X axis and Y axis together are in and/or define a horizontal plane and the Z axis is and/or defines a vertical axis. Axes described herein may be the reference axes shown in FIG. 1, axes parallel to or effectively or substantially parallel to the reference axes shown in FIG. 1 (e.g., axes translated in space with respect to the reference axes shown in FIG. 1), or axes of a coordinate system that is rotated in space with respect to the reference axes shown in FIG. 1. For example, a vertical axis may be the Z axis shown in FIG. 1 or may be an axis parallel to or effectively or substantially parallel to the Z axis shown in FIG. 1. Components of the systems described herein may be described in reference to a coordinate system associated with the component.

FIG. 2A is a schematic drawing showing a front, "beams-eye" view of the photon radiation treatment system described herein.

FIG. 2B is a schematic drawing showing a rear view of the photon radiation treatment system as viewed from the opposite direction relative to the view of FIG. 2A.

FIG. 2C is a schematic drawing showing a plan (overhead) view of the photon radiation treatment system.

FIG. 2D is a schematic drawing showing a side view of the photon radiation treatment system that is orthogonal to the views shown in FIG. 2A, FIG. 2B, and FIG. 2C.

FIG. 3A is a schematic drawing showing a front view of a medical imaging system.

FIG. 3B is a schematic drawing showing a front view of the medical imaging system of FIG. 3A and showing translation of a scanner ring of the medical imaging system.

FIG. 3C is a schematic drawing showing a plan view of the medical imaging system.

FIG. 3D is a schematic drawing showing a side view of the medical imaging system and an axis of rotation ρ about which rotates the gantry (220).

FIG. 3E is a schematic drawing showing a side view of the medical imaging system and rotation of the gantry around the axis of rotation ρ to provide a tilted configuration.

FIG. 3F is a schematic drawing showing a side view of the medical imaging system and rotation of the gantry around the axis of rotation ρ to provide a horizontal configuration.

FIG. 3G is a schematic drawing showing a plan view of the medical imaging system provided in an orientation that is rotated at an angle of approximately 20 to 45 degrees around a Z axis with respect to the orientation shown in FIG. 2C.

FIG. 3H is a schematic drawing showing the same plan view of the medical imaging system shown in FIG. 3G. In FIG. 3H, the major axis of the scanner bridge (231) and the beam axis (800) are indicated with dotted lines. As shown in FIG. 3H, rotating the medical imaging system as shown in FIG. 3G results in an angle ω of approximately 110 to 135 degrees between the beam axis (800) and the major axis of the scanner bridge (231).

FIG. 4A is a schematic drawing showing a plan view of the patient rotation system (300) structured to rotate around an axis of rotation (700) relative to a static source (e.g., beam delivery system) (100).

FIG. 4B is a schematic drawing showing a plan view of the patient rotation system (300) and rotation of the patient rotation system (300) and the patient (500) relative to the static source (e.g., beam delivery system) (100) during treatment with a beam (800), e.g., to provide rotational treatment of the patient.

FIG. 5 is a schematic drawing showing a cross-sectional view of a beam delivery system, including photon generator assembly (110), an adjustment ring assembly (124), a collimator assembly (130), a jaw assembly (140), a multileaf collimator (MLC) (150), a nozzle housing (190), and a shutter assembly (192). FIG. 5 also depicts electron beam (102) and various shaped photon beams (104, 106, 800).

FIG. 6A is a schematic drawing showing a cross-sectional view of the photon generator assembly (110) with the waveguide shield (118) covering the waveguide (114).

FIG. 6B is a schematic drawing showing a cross-sectional view of the photon generator assembly (110) with the waveguide shield (118) retracted following the arrow of FIG. 6A.

FIG. 7A is a drawing of the primary collimator (132) and the collimator housing (134) shown in its blank form before final machining. The primary collimator (132) and housing (134) are not shown to scale.

FIG. 7B is a drawing of the collimator assembly (130), after the collimator (132) has been press fit into the housing (134) and received final machining.

FIG. 8A is a schematic drawing showing a side view of a medical imaging system comprising a scanner ring and a static source (e.g., beam delivery system) (100). FIG. 8A shows a wall (620) of a treatment room. The source is in a storage position distal from the patient rotation system (not shown) and isocenter along the Y axis. The scanner ring is in an overhead position distal from the patient rotation system (not shown) and isocenter along the Z axis.

FIG. 8B is a schematic drawing showing a side view of the medical imaging system and translation of a scanner ring (250) of the medical imaging system from an overhead position to an imaging position. The medical imaging system comprising the scanner ring in the imaging position finds use in imaging a patient to acquire a medical image of a treatment volume of the patient comprising the isocenter (900).

FIG. 8C is a schematic drawing showing a side view of the medical imaging system and a translation of the scanner ring of the medical imaging system from the imaging position to the overhead position.

FIG. 8D is a schematic drawing showing a side view of the medical imaging system with the scanner ring in an overhead position and a translation of the source (e.g., beam delivery system) from a storage position to a treatment position proximal to the patient rotation system (not shown) and isocenter.

FIG. 8E is a schematic drawing showing a side view of the medical imaging system and the beam delivery system generating a beam (800) to contact the isocenter (900) with the beam (800).

FIG. 8F is a schematic drawing showing a side view of the medical imaging system shown in FIG. 8E after the beam generating system has been inactivated.

FIG. 8G is a schematic drawing showing a side view of the medical imaging system and a translation of the source from a treatment position to a storage position that is distal from the patient.

FIG. 8H is a drawing showing an isometric view of the beam delivery system in a treatment position.

FIG. 8I is a drawing showing an isometric view of the beam delivery system in a storage position.

FIG. 9A is a drawing showing an isometric view of the beam delivery system with a collimator at a 0-degree position.

FIG. 9B is a drawing showing an isometric view of the beam delivery system with a collimator rotated 15 degrees.

FIG. 9C is a schematic drawing showing steps of a method for rocking a multileaf collimator between a first position (I) and a second position (II).

FIG. 10A is a schematic drawing showing a side view of a medical imaging system and patient rotation system (partially occluded from view) in which the gantry of the medical imaging system and the patient rotation system are tilted to image and/or treat a patient in a tilted position. In FIG. 10A, the scanner ring is shown in an overhead position.

FIG. 10B is a schematic drawing showing a side view of the medical imaging system of FIG. 10A after the scanner ring has been translated to an imaging position.

It is to be understood that the figures are not necessarily drawn to scale, nor are the objects in the figures necessarily drawn to scale in relationship to one another. The figures are depictions that are intended to bring clarity and understanding to various embodiments of apparatuses, systems, and methods disclosed herein. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts. Moreover, it should be appreciated that the drawings are not intended to limit the scope of the present teachings in any way. Embodiments of the technology are described using the following numbered features:

100	beam delivery system (source)
102	electron beam
104	photon beam
106	photon beam
110	photon generator assembly
112	electron gun
113	cathode
114	waveguide
116	excitation target disk
118	waveguide shield
120	linear bearing rails
124	adjustment ring assembly
126	adjustment ring
128	mounting plate
130	collimator assembly
132	primary collimator
134	collimator housing
136	cutout
140	jaw assembly
142	upper jaw
144	lower jaw
150	multileaf collimator
152	leaves of multileaf collimator
190	nozzle housing
191	indentation of nozzle housing
192	shutter assembly
194	shutter
196	pulley mechanism
200	medical imaging system
211	first pillar
212	second pillar
220	gantry
221	first scanner arm
222	second scanner arm
230	scanner bridge
231	major axis of scanner bridge
250	scanner ring
255	bore
290	ingress/egress area
291	ingress/egress path
300	patient rotation system
500	patient
600	treatment room
610	floor
620	wall
700	axis of rotation
800	radiation beam
900	isocenter

DETAILED DESCRIPTION

Provided herein is technology relating to treating a patient having a disease and particularly, but not exclusively, to systems and methods for treating a cancer patient in an upright position with photon radiation. Embodiments of the technology provide a photon radiation treatment system comprising a medical imaging system, a patient rotation system, and a photon beam delivery system.

In this detailed description of the various embodiments, for purposes of explanation, numerous specific details are set forth to provide a thorough understanding of the

embodiments disclosed. One skilled in the art will appreciate, however, that these various embodiments may be practiced with or without these specific details. In other instances, structures and devices are shown in block diagram form. Furthermore, one skilled in the art can readily appreciate that the specific sequences in which methods are presented and performed are illustrative and it is contemplated that the sequences can be varied and still remain within the spirit and scope of the various embodiments disclosed herein.

All literature and similar materials cited in this application, including but not limited to, patents, patent applications, articles, books, treatises, and internet web pages are expressly incorporated by reference in their entirety for any purpose. Unless defined otherwise, all technical and scientific terms used herein have the same meaning as is commonly understood by one of ordinary skill in the art to which the various embodiments described herein belongs. When definitions of terms in incorporated references appear to differ from the definitions provided in the present teachings, the definition provided in the present teachings shall control. The section headings used herein are for organizational purposes only and are not to be construed as limiting the described subject matter in any way.

Definitions

To facilitate an understanding of the present technology, a number of terms and phrases are defined below. Additional definitions are set forth throughout the detailed description.

Throughout the specification and claims, the following terms take the meanings explicitly associated herein, unless the context clearly dictates otherwise. The phrase "in one embodiment" as used herein does not necessarily refer to the same embodiment, though it may. Furthermore, the phrase "in another embodiment" as used herein does not necessarily refer to a different embodiment, although it may. Thus, as described below, various embodiments of the invention may be readily combined, without departing from the scope or spirit of the invention.

In addition, as used herein, the term "or" is an inclusive "or" operator and is equivalent to the term "and/or" unless the context clearly dictates otherwise. The term "based on" is not exclusive and allows for being based on additional factors not described, unless the context clearly dictates otherwise. In addition, throughout the specification, the meaning of "a", "an", and "the" include plural references. The meaning of "in" includes "in" and "on."

As used herein, the terms "about", "approximately", "substantially", and "significantly" are understood by persons of ordinary skill in the art and will vary to some extent on the context in which they are used. If there are uses of these terms that are not clear to persons of ordinary skill in the art given the context in which they are used, "about" and "approximately" mean plus or minus less than or equal to 10% of the particular term and "substantially" and "significantly" mean plus or minus greater than 10% of the particular term.

As used herein, disclosure of ranges includes disclosure of all values and further divided ranges within the entire range, including endpoints and sub-ranges given for the ranges. As used herein, the disclosure of numeric ranges includes the endpoints and each intervening number therebetween with the same degree of precision. For example, for the range of 6–9, the numbers 7 and 8 are contemplated in addition to 6 and 9, and for the range 6.0–7.0, the numbers 6.0, 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, and 7.0 are explicitly contemplated.

As used herein, the suffix "-free" refers to an embodiment of the technology that omits the feature of the base root of the word to which "-free" is appended. That is, the term "X-free" as used herein means "without X", where X is a feature of the technology omitted in the "X-free" technology. For example, a "calcium-free" composition does not comprise calcium, a "mixing-free" method does not comprise a mixing step, etc.

Although the terms "first", "second", "third", etc. may be used herein to describe various steps, elements, compositions, components, regions, layers, and/or sections, these steps, elements, compositions, components, regions, layers, and/or sections should not be limited by these terms, unless otherwise indicated. These terms are used to distinguish one step, element, composition, component, region, layer, and/or section from another step, element, composition, component, region, layer, and/or section. Terms such as "first", "second", and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first step, element, composition, component, region, layer, or section discussed herein could be termed a second step, element, composition, component, region, layer, or section without departing from technology.

As used herein, the word "presence" or "absence" (or, alternatively, "present" or "absent") is used in a relative sense to describe the amount or level of a particular entity (e.g., component, action, element). For example, when an entity is said to be "present", it means the level or amount of this entity is above a pre-determined threshold; conversely,

when an entity is said to be "absent", it means the level or amount of this entity is below a pre-determined threshold. The pre-determined threshold may be the threshold for detectability associated with the particular test used to detect the entity or any other threshold. When an entity is "detected" it is "present"; when an entity is "not detected" it is "absent".

As used herein, an "increase" or a "decrease" refers to a detectable (e.g., measured) positive or negative change, respectively, in the value of a variable relative to a previously measured value of the variable, relative to a pre-established value, and/or relative to a value of a standard control. An increase is a positive change preferably at least 10%, more preferably 50%, still more preferably 2-fold, even more preferably at least 5-fold, and most preferably at least 10-fold relative to the previously measured value of the variable, the pre-established value, and/or the value of a standard control. Similarly, a decrease is a negative change preferably at least 10%, more preferably 50%, still more preferably at least 80%, and most preferably at least 90% of the previously measured value of the variable, the pre-established value, and/or the value of a standard control. Other terms indicating quantitative changes or differences, such as "more" or "less," are used herein in the same fashion as described above.

As used herein, a "system" refers to a plurality of real and/or abstract components operating together for a common purpose. In some embodiments, a "system" is an integrated assemblage of hardware and/or software components. In some embodiments, each component of the system interacts with one or more other components and/or is related to one or more other components. In some embodiments, a system refers to a combination of components and software for controlling and directing methods. For example, a "system" or "subsystem" may comprise one or more of, or any combination of, the following: mechanical devices, hardware, components of hardware, circuits, circuitry, logic design, logical components, software, software modules, components of software or software modules, software procedures, software instructions, software routines, software objects, software functions, software classes, software programs, files containing software, etc., to perform a function of the system or subsystem. Thus, the methods, system, components of systems, and apparatuses of the embodiments, or certain aspects or portions thereof, may take the form of program code (e.g., instructions) embodied in tangible media, such as floppy diskettes, CD-ROMs, hard drives, flash memory, or any other machine-readable storage medium wherein, when the program code is loaded into and executed by a machine,

such as a computer, the machine becomes an apparatus for practicing the embodiments. In the case of program code execution on programmable computers, the computing device generally includes a processor, a storage medium readable by the processor (e.g., volatile and non-volatile memory and/or storage elements), at least one input device, and at least one output device. One or more programs may implement or utilize the processes described in connection with the embodiments, e.g., through the use of an application programming interface (API), reusable controls, or the like. Such programs are preferably implemented in a high-level procedural or object-oriented programming language to communicate with a computer system. However, the program(s) can be implemented in assembly or machine language, if desired. In any case, the language may be a compiled or interpreted language and combined with hardware implementations.

As used herein, the term "structured to [verb]" means that the identified element or assembly has a structure that is shaped, sized, disposed, coupled, and/or configured to perform the identified verb. For example, a member that is "structured to move" is movably coupled to another element and includes elements that cause the member to move, or the member is otherwise configured to move in response to other elements or assemblies. As such, as used herein, "structured to [verb]" recites structure and not function. Further, as used herein, "structured to [verb]" means that the identified element or assembly is intended to, and is designed to, perform the identified verb.

As used herein, the term "associated" means that the elements are part of the same assembly and/or operate together or act upon/with each other in some manner. For example, an automobile has four tires and four hub caps. While all the elements are coupled as part of the automobile, it is understood that each hubcap is "associated" with a specific tire.

As used herein, the term "coupled" refers to two or more components that are secured, by any suitable means, together. Accordingly, in some embodiments, the statement that two or more parts or components are "coupled" shall mean that the parts are joined or operate together either directly or indirectly, e.g., through one or more intermediate parts or components.

As used herein, "directly coupled" means that two elements are directly in contact with each other. As used herein, "fixedly coupled" or "fixed" means that two components are coupled so as to move as one while maintaining a constant orientation relative to each other. Accordingly, when two elements are coupled, all portions of those elements are

coupled. A description, however, of a specific portion of a first element being coupled to a second element, e.g., an axle first end being coupled to a first wheel, means that the specific portion of the first element is disposed closer to the second element than the other portions thereof. Further, an object resting on another object held in place only by gravity is not "coupled" to the lower object unless the upper object is otherwise maintained substantially in place. That is, for example, a book on a table is not coupled thereto, but a book glued to a table is coupled thereto.

As used herein, the term "removably coupled" or "temporarily coupled" means that one component is coupled with another component in an essentially temporary manner. That is, the two components are coupled in such a way that the joining or separation of the components is easy and does not damage the components. Accordingly, "removably coupled" components may be readily uncoupled and recoupled without damage to the components.

As used herein, the term "operatively coupled" means that a number of elements or assemblies, each of which is movable between a first position and a second position, or a first configuration and a second configuration, are coupled so that as the first element moves from one position/configuration to the other, the second element moves between positions/configurations as well. It is noted that a first element may be "operatively coupled" to another without the opposite being true.

As used herein, the term "rotatably coupled" refers to two or more components that are coupled in a manner such that at least one of the components is rotatable with respect to the other.

As used herein, the term "translatably coupled" refers to two or more components that are coupled in a manner such that at least one of the components is translatable with respect to the other.

As used herein, the term "interference fit" refers to a fit between two parts in which the external dimension of a first part slightly exceeds the internal dimension of a second part into which fits the first part. Accordingly, an interference fit may be used to couple two parts using friction.

As used herein, the term "temporarily disposed" means that a first element or assembly is resting on a second element or assembly in a manner that allows the first element/assembly to be moved without having to decouple or otherwise manipulate the first element. For example, a book simply resting on a table, e.g., the book is not glued or fastened to the table, is "temporarily disposed" on the table.

As used herein, the term "correspond" indicates that two structural components are sized and shaped to be similar to each other and may be coupled with a minimum amount of friction. Thus, an opening which "corresponds" to a member is sized slightly larger than the member so that the member may pass through the opening with a minimum amount of friction. This definition is modified if the two components are to fit "snugly" together. In that situation, the difference between the size of the components is even smaller whereby the amount of friction increases. If the element defining the opening and/or the component inserted into the opening are made from a deformable or compressible material, the opening may even be slightly smaller than the component being inserted into the opening. With regard to surfaces, shapes, and lines, two or more "corresponding" surfaces, shapes, or lines have generally the same size, shape, and contours.

As used herein, a "path of travel" or "path," when used in association with an element that moves, includes the space an element moves through when in motion. As such, any element that moves inherently has a "path of travel" or "path."

As used herein, the statement that two or more parts or components "engage" one another shall mean that the elements exert a force or bias against one another either directly or through one or more intermediate elements or components. Further, as used herein with regard to moving parts, a moving part may "engage" another element during the motion from one position to another and/or may "engage" another element once in the described position. Thus, it is understood that the statements, "when element A moves to element A first position, element A engages element B," and "when element A is in element A first position, element A engages element B" are equivalent statements and mean that element A either engages element B while moving to element A first position and/or element A engages element B while in element A first position.

As used herein, the term "operatively engage" means "engage and move." That is, "operatively engage" when used in relation to a first component that is structured to move a movable or rotatable second component means that the first component applies a force sufficient to cause the second component to move. For example, a screwdriver may be placed into contact with a screw. When no force is applied to the screwdriver, the screwdriver is merely "coupled" to the screw. If an axial force is applied to the screwdriver, the screwdriver is pressed against the screw and "engages" the screw. However, when a rotational force is applied to the screwdriver, the screwdriver "operatively engages" the screw and causes the screw to rotate. Further, with electronic components, "operatively

engage" means that one component controls another component by a control signal or current.

As used herein, the term "number" shall mean one or an integer greater than one (e.g., a plurality).

As used herein, in the phrase "[x] moves between its first position and second position," or "[y] is structured to move [x] between its first position and second position," "[x]" is the name of an element or assembly. Further, when [x] is an element or assembly that moves between a number of positions, the pronoun "its" means "[x]," i.e., the named element or assembly that precedes the pronoun "its."

As used herein, a "radial side/surface" for a circular or cylindrical body is a side/surface that extends about, or encircles, the center thereof or a height line passing through the center thereof. As used herein, an "axial side/surface" for a circular or cylindrical body is a side that extends in a plane extending generally perpendicular to a height line passing through the center. That is, generally, for a cylindrical soup can, the "radial side/surface" is the generally circular sidewall and the "axial side(s)/surface(s)" are the top and bottom of the soup can.

As used herein, the word "unitary" means a component is created as a single piece or unit. That is, a component that includes pieces that are created separately and then coupled together as a unit is not a "unitary" component or body.

As used herein, a "coupling assembly" includes two or more couplings or coupling components. The components of a coupling or coupling assembly are generally not part of the same element or other component. As such, the components of a "coupling assembly" may not be described at the same time in the following description.

As used herein, a "coupling" or "coupling component(s)" is one or more component(s) of a coupling assembly. That is, a coupling assembly includes at least two components that are structured to be coupled together. It is understood that the components of a coupling assembly are compatible with each other. For example, in a coupling assembly, if one coupling component is a snap socket, the other coupling component is a snap plug, or, if one coupling component is a bolt, then the other coupling component is a nut.

As used herein, a "planar body" or "planar member" is a generally thin element including opposed, wide, generally flat surfaces as well as a thinner edge surface extending between the wide flat surfaces. The edge surface may include generally flat portions, e.g., as on a rectangular planar member, or be curved, as on a disk, or have any other shape.

As used herein, and when used in reference to communicating data or a signal, "in electronic communication" includes both hardline and wireless forms of communication.

As used herein, "in electric communication" or "in electrical communication" means that a current passes, or can pass, between the identified elements. Being "in electric communication" is further dependent upon an element's position or configuration. For example, in a circuit breaker, a movable contact is "in electric communication" with the fixed contact when the contacts are in a closed position. The same movable contact is not "in electric communication" with the fixed contact when the contacts are in the open position.

As used herein, the term "radiation source" or "source" refers to an apparatus that produces radiation (e.g., ionizing radiation) in the form of photons (e.g., described as particles or waves), e.g., a photon beam delivery system as described herein. In some embodiments, a radiation source comprises a linear accelerator ("linac") that produces a beam of photons or electrons that finds use in treating a cancer patient by contacting a tumor with the photon or electron beam. In some embodiments, the source produces electromagnetic waves, e.g., in the form of x-rays or gamma rays having a wavelength in the range of approximately 1 pm to approximately 1 nm). While it is understood that radiation can be described as having both wave-like and particle-like aspects, it is sometimes convenient to refer to radiation in terms of waves and sometimes convenient to refer to radiation in terms of particles. Accordingly, both descriptions are used throughout without limiting the technology and with an understanding that the laws of quantum mechanics provide that every particle or quantum entity is described as either a particle or a wave.

As used herein, the term "static source" refers to a source that does not revolve around a patient axis of rotation during use of the source for therapy. Some embodiments provide that a "static source" remains essentially fixed with respect to an axis passing through the patient and about which the patient rotates while the patient is being treated with a photon beam produced by the static source. While the patient may rotate around said axis to produce relative motion between the static source and the rotating patient that is equivalent to the relative motion of a source revolving around a static patient, a static source does not revolve around the patient rotation axis with reference to a third object or frame of reference (e.g., a treatment room in which a patient is positioned) during treatment while the patient is rotated around the patient rotation axis with respect to said

third object or said frame of reference (e.g., said treatment room in which said patient is positioned) during treatment.

A static source may be translated along one or more axes and/or may be rotated or revolved around one or more axes during installation, maintenance, or for beam alignment and adjustment. As described herein, a static source may be translated away from the patient to accommodate a component of an imaging system for imaging the patient and the static source may be translated toward the patient to position the static source for treatment of the patient.

As described herein, in some embodiments, a static source may translate (e.g., along an axis parallel or substantially parallel to the patient axis of rotation (e.g., in the Z direction)) during treatment of a patient and/or may revolve or rotate around an axis that is orthogonal to the patient rotation axis during treatment of a patient (e.g., an axis in the X or Y directions). For example, as described herein, a static source or a component thereof may rotate around the beam axis, e.g., during treatment of a patient. Further, a static source may translate, rotate, and/or revolve around the patient to position the static source prior to treatment of the patient or after treatment of the patient. In some embodiments, the "static source" is a photon source and thus may be referred to as a "static photon source".

A static source may be installed on a mobile platform and thus the static source may move with respect to the Earth and fixtures on the Earth as the mobile platform moves to transport the static source. Thus, the term "static source" may refer to a mobile "static source" provided that the mobile "static source" does not revolve around an axis passing through the patient and about which the patient rotates while the patient is being treated with a photon beam produced by the static source.

As used herein, the term "computed tomography" is abbreviated "CT" and refers both to tomographic and non-tomographic radiography. For instance, the term "CT" refers to numerous forms of CT, including but not limited to x-ray CT, positron emission tomography (PET), single-photon emission computed tomography (SPECT), and photon counting computed tomography. Generally, computed tomography (CT) comprises use of an opposed x-ray source and detector that revolve around a patient and subsequent reconstruction of images into different planes. In embodiments of CT (e.g., devices, apparatuses, and methods provided for CT) described herein, the x-ray source is a static source, and the patient is rotated with respect to the static source. Currents for x-rays used

in CT describe the current flow from a cathode to an anode and are typically measured in milliamperes (mA).

As used herein, the term "beam" refers to a stream of radiation (e.g., electromagnetic wave and/or or particle radiation). In some embodiments, the beam is produced by a source and is restricted to a small-solid angle. In some embodiments, the beam is collimated. In some embodiments, the beam is generally unidirectional. In some embodiments, the beam is divergent. In some embodiments, the beam is a photon beam, and in some embodiments, the beam is an x-ray beam.

As used herein, the term "patient" or "subject" refers to a mammalian animal that is identified and/or selected for imaging and/or treatment with radiation. Accordingly, in some embodiments, a patient or subject is contacted with a beam of radiation, e.g., a primary beam produced by a radiation source. In some embodiments, the patient or subject is a human. In some embodiments, the patient or subject is a veterinary or farm animal, a domestic animal or pet, or animal used for clinical research. In some embodiments, the subject or patient has a disease (e.g., a cancer) and/or the subject or patient has either been recognized as having or at risk of having a disease (e.g., a cancer).

As used herein, the term "imaging volume" or "treatment volume" refers to the volume (e.g., tissue) of a patient that is selected for imaging and/or treatment with radiation. For example, in some embodiments, the "treatment volume" or "imaging volume" comprises a tumor in a patient (e.g., a patient). As used herein, the term "healthy tissue" refers to the volume (e.g., tissue) of a patient that is not and/or does not comprise the treatment volume. In some embodiments, the imaging volume is larger than the treatment volume and comprises the treatment volume.

Embodiments of the technology described herein are described in relation to a coordinate system that comprises an X axis, a Y axis, and a Z axis defined with respect to a radiation beam and axis of rotation of a patient and/or a patient rotation system. See FIG. 1, showing a drawing of a treatment room (600) comprising a floor (610), a wall (620), a radiation beam (800) produced by a source (100), and an axis of rotation (700) of the patient. The isocenter (900) is shown at the intersection of the radiation beam (800) and the axis of rotation (700) of the patient. As shown in FIG. 1, embodiments use a coordinate system in which the X axis and Y axis together are in and/or define a horizontal plane and the Z axis is and/or defines a vertical axis. With respect to a patient positioned on the PRS, the X axis is a left-right, horizontal, or frontal axis; the Y axis is an anteroposterior,

dorsoventral, or sagittal axis; and the Z axis is a sagittal or longitudinal axis. The X axis and the Y axis together are in and/or define a horizontal, transverse, and/or axial plane. The Y axis and the Z axis together are in and/or define a sagittal or longitudinal plane. The X axis and the Z axis together are in and/or define a frontal or coronal plane.

Accordingly, in some embodiments, descriptions of movements as "forward" or "backward" are movements along the Y axis; descriptions of movements as "left" or "right" are movements along the X axis; and descriptions of movements as "up" and "down" are movements along the Z axis. Furthermore, a rotation described as "roll" is a rotation (e.g., through an angle φ) around the Y axis; a rotation described as "pitch" is a rotation (e.g., through an angle ψ) around the X axis; and a rotation described as "yaw" is a rotation (e.g., through an angle θ) around the Z axis. Thus, in some embodiments, technologies are described as having six degrees of freedom, e.g., translations along one or more of the X, Y, and/or Z axes and rotations around one or more of the X, Y, and/or Z axes.

The axis of rotation (700) of the patient and the radiation beam (800), and thus the coordinate system, may be rotated in space with respect to the treatment room, e.g., to treat a patient leaning backward with respect to the treatment room or in other treatment postures that are not necessarily aligned with the walls and corners of the treatment room.

As used herein, the term "perched position" refers to a patient in a generally standing position with a torso angled posteriorly with respect to a vertical axis, optionally also having bent knees.

Photon radiation treatment system

The technology provides a photon radiation treatment system comprising a photon beam delivery system (100), a medical imaging system (200), and a patient rotation system (300). The patient rotation system (300) supports a patient in an upright position. The beam delivery system (100) is a static source. In some embodiments, the beam delivery system (100) may be translated away from a patient to a storage position to provide clearance for positioning a scanner ring of the medical imaging system at an imaging position to image the patient. FIG. 2A is a front view ("beams-eye view") of the photon radiation treatment system as seen from the photon beam delivery system (100) that shows the medical imaging system (200) and the patient rotation system (300). FIG. 2B shows a rear view from the opposite direction relative to the view in in FIG. 2A. FIG. 2B shows the photon beam delivery system (100), the medical imaging system (200), and the patient rotation system

(300). FIG. 2C is a plan (overhead) view showing the photon beam delivery system (100), the medical imaging system (200), and the patient rotation system (300), which is occluded from view by a portion of the medical imaging system (200). FIG. 2D is a side view that is orthogonal to the views shown in FIG. 2A, FIG. 2B, and FIG. 2C. FIG. 2D shows the photon beam delivery system (100), the medical imaging system (200), and the patient rotation system (300), which is occluded from view by a portion of the medical imaging system (200).

Some embodiments and aspects of the medical imaging system (200) are described in U.S. Pat. No. 11,918,397 ("Multi-axis medical imaging"), which is expressly incorporated herein by reference. Some embodiments and aspects of the patient rotation system (300) are described in U.S. Pat. No. 11,529,109 ("Patient positioning apparatus") and in U.S. Pat. App. Pub. No. 20230172566 ("Patient positioning system"), each of which is expressly incorporated herein by reference.

Medical imaging system

Embodiments of the photon radiation treatment system comprise a medical imaging system (200). As shown in FIG. 3A to 3C, the medical imaging system (200) comprises a first scanner pillar (211) and a second scanner pillar (212). A gantry (220) comprises a first scanner arm (221), a second scanner arm (222), and a scanner bridge (230). The gantry (220) is rotatably coupled to the first scanner pillar (211) and the second scanner pillar (212). In particular, the first scanner arm (221) is rotatably coupled to the first scanner pillar (211), and the second scanner arm (222) is rotatably coupled to the second scanner pillar (212). The gantry (220) may be rotated as a unit around an axis of rotation rho (ρ) (see FIG. 3D to 3F, discussed below).

The medical imaging system (200) comprises a scanner ring (250) translatably coupled to the first scanner arm (221) and to the second scanner arm (222). The scanner ring (250) comprises a photon (e.g., x-ray) source and a photon detector on opposite sides of a bore (255) surrounded by the scanner ring (250), e.g., to provide a computerized tomography (CT) imaging system. As shown in FIG. 3B, the scanner ring (250) may be translated along the first scanner arm (221) and second scanner arm (222). In particular embodiments when the first scanner arm (221) and the second scanner arm (222) are positioned in an upright (vertical) position, the scanner ring (250) may be translated in the Z direction (e.g., "up" and "down") along the first scanner arm (221) and second scanner arm (222), e.g., to position the scanner ring (250) such that an upright patient is located within

the bore (255) of the scanner ring (250). By rotating the gantry (220) around the axis of rotation rho (ρ), the scanner ring (250) is also rotated such that a patient may be imaged in upright, horizontal, tilted, and other positions. The scanner ring (250) may be translated along the first scanner arm (221) and second scanner arm (222) when the first scanner arm (221) and second scanner arm are vertical, horizontal, or in a tilted position between a vertical and horizontal position.

For example, as shown in FIG. 3D to 3F, the gantry (220) (comprising the first scanner arm (221), the second scanner arm (222), and the scanner bridge (230)) and scanner ring (250) may rotate around the axis of rotation rho (ρ). The gantry (220) may rotate through an angle of approximately 5 to 100 degrees (e.g., 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, or 100 degrees) to position the scanner ring (250) and the bore (255) of the scanner ring in a position relative to the Z axis to acquire medical images of a patient in postures that are tilted with respect to the Z axis (e.g., as shown in FIG. 3E) and in postures that are horizontal (e.g., substantially or effectively horizontal), e.g., prone or supine positions (e.g., as shown in FIG. 3F). The scanner ring (250) may be translated along the first scanner arm (221) and second scanner arm (222) when the gantry (220) has been rotated as described above, e.g., to positions exemplified in FIG. 3D, FIG. 3E, and FIG. 3F.

Accordingly, the medical imaging system may be tilted (e.g., as shown in FIG. 3E) to obtain medical images of a patient in a tilted posture, which may find use in planning treatment of the patient with radiotherapy in the same tilted posture (e.g., as described herein). In some embodiments, methods comprise treating a patient in a tilted position, wherein the patient is tilted back approximately 15 degrees (e.g., 12.0, 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 13.0, 13.1, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7, 13.8, 13.9, 14.0, 14.1, 14.2, 14.3, 14.4, 14.5, 14.6, 14.7, 14.8, 14.9, 15.0, 15.1, 15.2, 15.3, 15.4, 15.5, 15.6, 15.7, 15.8, 15.9, 16.0, 16.1, 16.2, 16.3, 16.4, 16.5, 16.6, 16.7, 16.8, 16.9, 17.0, 17.1, 17.2, 17.3, 17.4, 17.5, 17.6, 17.7, 17.8, 17.9, or 18.0 degrees), e.g., to place the head more posterior and the feet more anterior with respect to the patient body. Accordingly, embodiments of methods are provided that comprise imaging the patient in a tilted position wherein the patient is tilted back during imaging at the same angle in which treating the patient will be performed. A patient provided in a tilted position is more stable than a patient provided in an upright, untilted position (i.e., a position that is aligned, or that is effectively or substantially

aligned, with a Z axis or a position in which the patient is tilted less than 5 to 10 degrees with respect to a Z axis).

The beam delivery system (100) may be translated along a Y axis to place the beam delivery system (100) proximal to the patient rotation system (300), patient (500), and/or isocenter (900) during treatment of the patient (500). When not in use for treating a patient (500), the beam delivery system (100) may be translated along the Y axis to locate it in a storage position distal from the patient rotation system (300). In some embodiments, the storage position is behind a wall (620) of the treatment room (600) as shown in FIG. 1 and in more detail in FIG. 6H and FIG. 6I. In some embodiments, methods of treatment comprise a coordinated movement of the beam delivery system (100) and the scanner ring (500) as described below and shown in FIG. 6A to FIG. 6G.

In some embodiments, e.g., as shown in FIG. 3G, the medical imaging system (200) is provided in an orientation in which the medical imaging system (200) is rotated at an angle ζ that is approximately 20 to 45 degrees around the Z axis with respect to the orientation shown in FIG. 2C. In other words, as shown in FIG. 3H, embodiments provide that the medical imaging system (200) is rotated around a Z axis such that a major axis of the scanner bridge (231) (e.g., a line connecting the first scanner pillar and second scanner pillar) forms an angle ω with the beam axis (800) that is approximately 110 to 135 degrees (e.g., 100, 105, 110, 115, 120, 125, 130, 135, 140, or 145 degrees). For reference, the embodiment shown in FIG. 2C provides the medical imaging system (200) at an angle ω that is approximately 90 degrees.

As shown in FIG. 3G and FIG. 3H, a medical imaging system (200) provided in such a rotated orientation produces an enlarged patient ingress/egress area (290) relative to the embodiment shown in FIG. 2C. The enlarged patient ingress/egress area (290) provides improved access to the patient rotation system (300) for the patient, e.g., along an unimpeded ingress/egress path (291). Accordingly, in some embodiments, providing the medical imaging system (200) in a rotated orientation provides a patient ingress/egress area (290) and/or an unimpeded ingress/egress path (291) for patient movement along which a patient may efficiently enter and exit the patient rotation system (300) and/or medical imaging system (200) for imaging and/or treatment.

Patient rotation system

Embodiments of the photon radiation treatment system comprise a patient rotation system (300). As shown in FIG. 4A, the patient rotation system (300) is structured to rotate around an axis of rotation (700). In some embodiments, the axis of rotation (700) passes through an isocenter (900) associated with treatment of a patient and the target volume. The patient rotation system (300) rotates with respect to a source (e.g., a static source) (100). As shown in FIG. 4B, a patient (500) positioned on the patient rotation system (300) is rotated around the axis of rotation during treatment with the beam (800) produced by the source (100).

Beam delivery system

Embodiments of the photon radiation system comprise a beam delivery system (100). As shown in cross-section in FIG. 5, the beam delivery system is structured to provide a controlled beam of photon radiation aimed at a treatment volume within the patient, while also providing sufficient shielding and beam shaping systems to mitigate the beam's effect on healthy tissue. In some embodiments, the beam delivery system (100) comprises a photon generator assembly (110), an adjustment ring assembly (124), a collimator assembly (130), a jaw assembly (140), a multileaf collimator (MLC) (150), a nozzle housing (190), and a shutter assembly (192).

In some embodiments, the photon generator assembly (110) comprises an electron gun (112), a waveguide (114), an excitation target disk (116), and a waveguide shield (118). The photon generator assembly first produces a narrow beam of electrons (102) by the heating of a cathode (113) positioned at the distal end of the waveguide (114). The waveguide (114) then uses focuses and directs the beam of electrons in the negative Y direction to a target disk (116) on the proximal end of the waveguide (114). In some embodiments, the target disk (116) is made from a tungsten alloy or another heavy metal. When the beam of electrons (102) collides with target disk (116), the excitation produces a beam of high energy photons (104) (i.e., x-rays). The beam (104) is substantially conical in shape, increasing radially as moves in the negative Y direction toward the patient. In some embodiments, the photon generator assembly (110) further comprises a waveguide shield (118), sized and configured to fit over the waveguide (114) and provide shielding from stray high energy particles (i.e., scatter radiation). As shown in more detail in FIGS. 6A and 6B, in some embodiments, the waveguide shield (118) is configured to run along a pair of linear bearing rails (120). In some embodiments, the waveguide shield (118) is able to move in the

positive Y direction away from the rest of the system (100), revealing the waveguide (114) inside. This allows for easier installation and access to the waveguide (114) during maintenance.

Referring again to FIG. 5, in some embodiments, the waveguide (114) is coupled to an adjustment ring assembly (124) that allows for granular adjustment of the photon generator assembly's position and orientation, thus providing proper alignment of the photon beam (800) to the rest of the system (100). The adjustment ring assembly comprises a convex adjustment ring (126) and a concave mounting plate (128). The adjustment ring (126) is coupled to the waveguide (114), with its spherical surface abutting a corresponding surface of the mounting plate (128). The two abutting surfaces follow the same spherical profile allowing them to maintain contact while sliding relative to each other. This freedom of motion allows for granular adjustment of the beam's (102) orientation relative to the rest of the system (100) about the Z and X axes, similar to a ball and socket joint. In some embodiments, the adjustment ring assembly (124) includes fasteners securing the adjustment ring (126) to the mounting plant (128) at a desired orientation.

In some embodiments, the beam of photons (104) passes through a collimator assembly (130). In some embodiments, the primary collimator assembly (130) includes a primary collimator (132), a collimator housing (134), and a cutout (136) formed in the primary collimator (132). The primary collimator's function is, among other things, to form the beam (104) to a desired shape and minimize scatter radiation. In some embodiments, the primary collimator (132) is a cylinder formed of tungsten with a truncated square pyramidal cutout (136) oriented with its apex positioned distal to its square base, sized and configured to shape the substantially conical beam (104) into a substantially pyramidal beam (106). In some embodiments, the housing (134) is formed of stainless steel as a blank with a central bore. See FIG. 7A. The collimator (132) is then press fit into the central bore (producing an interference fit), and the surrounding housing is then machined to its final shape using features of the collimator (132) as a datum. See FIG. 7B. This technique allows for the manufacturing and implementation of a simplified composite part without the need for additional tolerance correcting components (i.e. a tolerance stack), thereby reducing the overall size of the system (100).

Referring again to FIG. 5, in some embodiments, the beam (106) passes through a jaw assembly (140), comprising an upper jaw (142) and a lower jaw (144). The jaw assembly (140) functions to further shape the photon beam (106) and shield against scatter radiation.

In some embodiments, the upper and lower jaws (142, 144) are sized and configured to open and close so as to further shape the photon beam (106). In some embodiments, the upper jaw (142) is lowered such that the upper edge (i.e. furthest in the positive Z direction) of photon beam (106) is aligned with the uppermost open leaf of the multileaf collimator (150), and similarly, the lower jaw (144) is raised such that the lower edge (i.e. furthest in the negative Z direction) of photon beam (106) is aligned with the lowermost open leaf of the multileaf collimator (150).

In some embodiments, the photon beam (106) passes through a MLC (150). In some embodiments, the MLC (150) comprises a plurality of leaves (152), wherein each leaf is translationally coupled to a motor that translates the leaves into positions to shape the beam (106) into the final shaped beam (800). Multileaf collimators are discussed in Boyer (July 2001) "Basic applications of multileaf collimators", AAPM Report No. 72 (Report of Task Group No. 50, Radiation Therapy Committee), published for the American Association of Physicists in Medicine by Medical Physics Publishing, incorporated herein by reference. Embodiments of the technology provide an MLC having a leaf speed of approximately 10 cm/s for the field projected to the isocenter (e.g., as provided by physical movement of individual leaves at a speed of approximately 5 cm/s). In some embodiments, the MLC (150) is positioned within a nozzle housing (190). As discussed further herein, in some embodiments, the nozzle housing includes an indentation (191) allowing for clearance for the patient and/or patient rotation system.

As discussed further herein, in some embodiments, the system 100 includes a shutter assembly (192), comprising a shutter (194) and pulley mechanism (196). In some embodiments, the pulley mechanism (196) is configured to automatically lower the shutter (194) when the nozzle housing (190) is extended and automatically raise the shutter (194) when the nozzle housing (190) is retracted.

Methods

The technology provided herein relates to various methods for imaging and/or for treating a patient. In some embodiments, the technology described herein provides a method for treatment of a patient with photon radiation. Medical diagnostic images provided by the medical imaging system of the patient (e.g., in an upright position) are used to plan radiological treatment of the patient (e.g., in an upright position) using a photon beam generated by the beam delivery system. In some embodiments, the patient rotation system

stabilizes and supports a patient in an upright position, and both the process of medical imaging and the process of radiological treatment are performed using the same patient rotation system to support and position the patient.

Therapeutic methods

Embodiments of the technology relate to methods of treating a patient. For example, in some embodiments, methods comprise selecting a patient in need of a treatment with radiation. In some embodiments, the patient is a cancer patient, e.g., a patient having a tumor. In some embodiments, the patient has an arteriovenous malformation. In some embodiments, the radiation is a photon beam (e.g., an x-ray beam). Accordingly, in some embodiments, methods comprise contacting a tumor of a patient (i.e., a treatment volume) with photon radiation. In some embodiments, the patient is positioned on a patient rotation system as described herein and the photon radiation is provided by a photon beam generation system as described herein.

In some embodiments, methods of treating a patient comprise imaging the patient. In some embodiments, imaging the patient is performed to provide medical images of the patient that find use in planning a treatment of the patient with photon radiation. In some embodiments, imaging the patient is performed to provide medical images of the patient that find use in verifying that a patient has been positioned correctly for treatment with photon radiation. In some embodiments, imaging the patient is performed to provide medical images of the patient that find use in adjusting a patient position prior to treatment with photon radiation. In some embodiments, imaging the patient is performed after the patient is treated with photon radiation, e.g., to provide medical images of the patient that find use in monitoring the effectiveness of the treatment. In some embodiments, methods of treating a patient comprise multiple treatment sessions of treating the patient with radiation and multiple imaging sessions of imaging the patient to provide images that find use in monitoring progress of treatment, that find use in modifying treatment plans, or that find use in providing information for determining if alternative or additional treatments of the patient may be effective (e.g., surgery, chemotherapy, etc.) In some embodiments, a patient is imaged using a medical imaging system as described herein.

In some embodiments, treatment is performed using the photon radiation treatment system comprising a photon beam delivery system, a medical imaging system, and a patient rotation system as described herein.

In some embodiments, a patient is treated with a photon beam while the patient is in an upright position (e.g., standing, sitting, kneeling, perched, tilted position (e.g., leaning backward), tilted leaning forward).

In some embodiments, a patient is treated with a photon beam while the patient is rotating around a patient axis of rotation.

Thus, embodiments of the technology relate to the disclosed photon radiation treatment system and methods of using it or components thereof for treating a patient with radiation, e.g., to kill undesirable tissue or cells. In some embodiments, a patient has an undesirable tissue or cell that was produced from transformation, e.g., a tumor, a cancer, or a neoplasm. As used herein, the term "cancer" includes a wide variety of malignant solid neoplasms that may be caused by viral infection, naturally occurring transformation, or exposure to environmental agents. The term "cancer" includes metastases from primary tumors.

Coordinated movement of beam delivery system and scanner ring

During treatment, the beam delivery system is positioned proximal to the patient (i.e., in a treatment position) to maximize delivery of radiation to the treatment volume and to minimize the spread of the beam during delivery of the beam and minimize exposure of healthy tissue to radiation. When not in use for treatment, the beam delivery system is positioned in a storage position within a wall of the treatment room.

An exemplary method for treatment of a patient is shown schematically in FIG. 8A to FIG. 8G. FIG. 8A shows a scanner ring (500) of a medical imaging system and a beam delivery system (100) in a storage position (e.g., distal from a patient rotation system in a Y direction). In the embodiment shown in FIG. 8A, the beam delivery system (100) is located in a storage position within a wall (620) of a treatment room and the scanner ring (500) is positioned in an overhead position (e.g., distal from a patient rotation system in a Z direction). When the beam delivery system (100) is in a storage position, the scanner ring (500) may be translated in a Z direction to position the scanner ring (500) in a location for use in medical imaging of a patient (e.g., to acquire an image of a portion (e.g., a treatment volume) of the patient comprising the isocenter (900)). That is, positioning the beam

delivery system (100) in the storage position provides clearance in space for translation of the scanner ring (500) along a Z axis to a position for use in imaging the patient (e.g., for imaging a portion (e.g., a treatment volume) of the patient comprising the isocenter (900)). Furthermore, when the beam delivery system (100) is in the storage position and the scanner ring (500) is positioned in an overhead position, the patient rotation system is accessible for placing a patient in a posture for imaging and/or for treatment of the patient. Accordingly, embodiments of methods for treatment of a patient comprise positioning a beam delivery system in a storage position (e.g., distal from the patient rotation system in a Y direction), positioning a scanner ring in an overhead position (e.g., distal from the patient rotation system in a Z direction), and placing a patient on a patient rotation system in a posture for imaging and/or for treatment.

FIG. 8B shows a step of translating the scanner ring (500) in a Z direction to position the scanner ring (500) in a location for use in medical imaging of a patient (e.g., to acquire an image of a portion (e.g., a treatment volume) of the patient comprising the isocenter (900)). Accordingly, embodiments of methods provided herein comprise translating a scanner ring from an overhead position (e.g., distal from the patient rotation system in a Z direction) to an imaging position (e.g., surrounding the patient and thus in a position for use in acquiring a medical image of a portion (e.g., a treatment volume) of the patient comprising the isocenter (900)). Furthermore, embodiments of methods comprise acquiring a medical image (e.g., a CT scan) of the patient (e.g., a portion (e.g., a treatment volume) of the patient comprising the isocenter) when the scanner ring is in the imaging position. In some embodiments, the medical image of the patient finds use in planning a radiological treatment of the patient with a photon beam. In some embodiments, the medical image of the patient finds use in verifying the position of the patient (e.g., of the treatment volume) with respect to the patient rotation system, the axis of rotation of the patient rotation system, and/or the treatment beam prior to treatment of the patient with a photon beam. In some embodiments, the medical image of the patient finds use in adjusting the position of the patient (e.g., of the treatment volume) with respect to the patient rotation system, the axis of rotation of the patient rotation system, and/or the treatment beam prior to treatment of the patient with a photon beam.

FIG. 8C shows a step of translating the scanner ring (500) in a Z direction to position the scanner ring in the overhead position. In some embodiments, the scanner ring is translated to the overhead position after imaging the patient to acquire a medical image

(e.g., a CT scan) of the patient (e.g., of a portion (e.g., a treatment volume) of the patient comprising the isocenter). Accordingly, embodiments of methods provided herein comprise translating a scanner ring from an imaging position (e.g., surrounding the patient treatment volume) to an overhead position (e.g., distal from the patient and patient rotation system in the Z direction).

FIG. 8D shows a step of translating the beam delivery system (100) in a Y direction from the storage position to locate the beam delivery system in a position proximal to the patient rotation system, patient, and/or isocenter for use in treating a patient (e.g., for delivering a photon (e.g., x-ray) beam to the treatment volume). Accordingly, embodiments of methods comprise translating a beam delivery system from a storage position (e.g., distal from the patient rotation system, patient, and/or isocenter in the Y direction) to a treatment position (e.g., proximal to the patient rotation system, patient, and/or isocenter).

FIG. 8E shows a step of generating a photon beam (800) by the beam delivery system (100). As shown in FIG. 8E, the patient (e.g., a portion (e.g., a treatment volume) of the patient comprising the isocenter (900)) is contacted with a photon (e.g., x-ray) beam when the beam delivery system is located in a treatment position. Furthermore, as shown in FIG. 8E, the patient (e.g., a portion (e.g., a treatment volume) of the patient comprising the isocenter (900)) is contacted with a photon (e.g., x-ray) beam when the medical imaging system is located in an overhead position. Accordingly, embodiments of methods comprise generating a photon beam by the beam delivery system and, in some embodiments, methods comprise contacting a patient (e.g., a portion (e.g., a treatment volume) of the patient comprising the isocenter (900)) with a photon beam. In some embodiments, the photon beam is an x-ray beam. FIG. 8F shows the beam delivery system in the treatment position after the treatment of the patient, e.g., when the generation of the beam by the beam delivery system has ceased.

FIG. 8G shows a step of translating the beam delivery system (100) in a Y direction from the treatment position to locate the beam delivery system in a storage position distal from the patient rotation system, patient, and/or isocenter. As noted above, some embodiments provide that the storage position is within a wall (620) of a treatment room. Accordingly, embodiments of methods comprise translating a beam delivery system from a treatment position (e.g., proximal to the patient rotation system, patient, and/or isocenter in the Y direction) to a storage position (e.g., distal from the patient rotation system, patient, and/or isocenter in the Y direction). When the beam delivery system (100) is in the

storage position and the scanner ring (500) is positioned in an overhead position, immobilization of the patient may be disengaged, and the patient may exit the patient rotation system (e.g., through a patient ingress/egress area (e.g., as shown in FIG. 2C)). Accordingly, embodiments of methods for treatment of a patient comprise positioning a beam delivery system in a storage position (e.g., distal from the patient rotation system, patient, and/or isocenter in the Y direction) and allowing the patient to exit from the patient rotation system.

Shutter assembly

In some embodiments, the beam delivery system is located in a storage position within a wall when not in use for beam delivery. For instance, in some embodiments, the beam delivery system (e.g., a nozzle housing (190) of the beam delivery system) is retracted to a position that is flush with the wall fascia, e.g., to provide sufficient clearance in space for deployment of the scanner ring to the imaging position as described herein. In some embodiments, linear motion units are operatively engaged with the beam delivery system and are structured to translate the beam delivery system in a Y direction, thus providing the beam delivery system in the treatment position and in the storage position. For example, FIG. 8I shows an embodiment of the beam delivery system (100) when the beam delivery system (100) is in the treatment position (e.g., the beam delivery system (100) is proximal to the patient and patient rotation system). As shown in FIG. 8H, in some embodiments, the beam delivery system (100) comprises a nozzle housing (190) and a shutter assembly (192). The shutter assembly (192) further comprises a shutter (194) and pulley mechanism (196).

Further, as shown in FIG. 8H, in some embodiments, the nozzle housing (190) comprises an indentation or "cut out" (191) at the lower portion of the nozzle housing (190). The indentation (191) in the nozzle housing (190) is provided so that the patient and/or patient rotation system does not collide with the beam delivery system (100) when the nozzle beam delivery system (100) is in the treatment position (e.g., proximal to the patient) and the patient and patient rotation system are rotating during treatment of the patient. In other words, the indentation (191) of the nozzle housing (190) provides clearance in space for the rotating patient and/or patient rotation system.

When the beam delivery system (100) is translated to the storage position, e.g., such that the front surface of the nozzle housing (190) is flush with the wall (620), the presence

of the indentation (191) leaves an open void in the wall as seen from the patient rotation system that would be seen by the patient. Thus, as shown in FIG. 8I, in some embodiments, the beam delivery system (100) comprises a shutter (194) of the shutter assembly (192) that translates into a position that cover the open void in the wall when the beam delivery system (100) is located in the storage position. The shutter assembly (192) is provided behind the wall (620) of the treatment room, i.e., the wall (620) is between the shutter assembly (192) and the patient rotation system and the patient when the patient is positioned on the patient rotation system. Accordingly, the shutter (194) closes off the void that is produced when the beam delivery system (100) is retracted into the wall (620). In some embodiments, the shutter assembly (192) comprises a pulley mechanism (196) that is operatively engaged with the shutter (194). The pulley mechanism (196) is configured to automatically lower the shutter (194) when the beam delivery system (100) (e.g., the nozzle housing (190)) is extended in the treatment position and automatically raise the shutter (194) when the beam delivery system (100) (e.g., the nozzle housing (190)) is retracted to the storage position.

Rocking multileaf collimator

In some embodiments, the technology provides methods of generating a photon beam with a beam generation system comprising a multileaf collimator. In some embodiments, the technology provides methods of treating a patient with photons (e.g., x-rays) produced by a beam delivery system comprising a multileaf collimator. Rotating a collimator has been used in radiation therapy to maximize conformance of the radiation field to the target volume (e.g., tumor), to provide increased field sizes, to mitigate interleaf leakage, to reduce treatment times, and to minimize exposure of normal tissue to radiation dose. See, e.g., Otto (2002) "Enhancement of IMRT delivery through MLC rotation" Phys Med Biol. 47: 3997–4017; Kim (2018) "Optimal collimator rotation based on the outline of multiple brain targets in VMAT" Radiation Oncology 13: 88; and Sandrini (2018) "Evaluation of collimator rotation for volumetric modulated arc therapy lung stereotactic body radiation therapy using flattening filter free" Applied Radiation and Isotopes 141:257–260, each of which is incorporated herein by reference. See also Lyu (2018) "VMAT optimization with dynamic collimator rotation" Med. Phys. 45: 2399–2410, incorporated herein by reference. In general, conventional technologies rotate a collimator at least 90 degrees, e.g., through a

full 360 degrees or through 180 degrees in one direction and 180 degrees in the opposite direction.

However, rotating the collimator provided herein more than 45 to 90 degrees with the beam delivery system in the treatment position (e.g., proximal to the patent and patient rotation system) would result in a collision between the beam delivery system and the patient or patient rotation system as the patient or patient rotation system rotates during treatment. Surprisingly, the benefit of rotating the collimator may be provided by rotating the collimator through relatively small rotation angles (e.g., approximately 15 degrees from a 0-position or approximately 30 degrees between two alternating positions), which find use in the technology described herein.

Thus, in contrast to conventional technologies, the technology provided herein rocks the multileaf collimator back and forth between a first position and a second position that are separated by an angle of 30 degrees, which is smaller than the angle of rotation typically used in previous methods comprising rotating a multileaf collimator more than 30 degrees, e.g., up to 90, 180, or 360 degrees. In other words, methods comprise rotating the multileaf collimator alternately in two directions of rotation around the beam axis through an angle of approximately 30 degrees between a first position that is rotated approximately 15 degrees in a first direction with respect to the horizontal axis and a second position that is rotated approximately 15 degrees in a second direction with respect to the horizontal axis, where the rotation in the second direction is a rotation in the opposite direction to the rotation in the first direction. Thus, when the first direction of rotation is clockwise, the second direction of rotation is counterclockwise; when the first direction of rotation is counterclockwise, the second direction of rotation is clockwise. In alternative terms, when the first direction of rotation is in the positive direction, the second direction of rotation is in the negative direction; when the first direction of rotation is in the negative direction, the second direction of rotation is in the positive direction. Accordingly, embodiments of the technology that rock the multileaf collimator may maximize conformance of the radiation field to the target volume (e.g., tumor), provide increased field sizes, mitigate interleaf leakage, reduce treatment times, and minimize exposure of normal tissue to radiation dose in the disclosed system comprising a rotating patent and patient rotation system without introducing risk of collisions.

In particular, embodiments of methods provided herein comprise dynamically rocking the multileaf collimator back and forth around the beam axis while generating a

photon beam – i.e., by alternately rotating the multileaf collimator around the beam axis to a first position that is rotated approximately 15 degrees (e.g., 10.0, 10.1, 10.2, 10.3, 10.4, 10.5, 10.6, 10.7, 10.8, 10.9, 11.0, 11.1, 11.2, 11.3, 11.4, 11.5, 11.6, 11.7, 11.8, 11.9, 12.0, 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 13.0, 13.1, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7, 13.8, 13.9, 14.0, 14.1, 14.2, 14.3, 14.4, 14.5, 14.6, 14.7, 14.8, 14.9, 15.0, 15.1, 15.2, 15.3, 15.4, 15.5, 15.6, 15.7, 15.8, 15.9, 16.0, 16.1, 16.2, 16.3, 16.4, 16.5, 16.6, 16.7, 16.8, 16.9, 17.0, 17.1, 17.2, 17.3, 17.4, 17.5, 17.6, 17.7, 17.8, 17.9, 18.0, 18.1, 18.2, 18.3, 18.4, 18.5, 18.6, 18.7, 18.8, 18.9, 19.0, 19.1, 19.2, 19.3, 19.4, 19.5, 19.6, 19.7, 19.8, 19.9, or 20.0 degrees) in a first direction with respect to the horizontal axis during generation of the photon (e.g., x-ray) beam and rotating the multileaf collimator around the beam axis to a second position that is rotated approximately 15 degrees (e.g., 10.0, 10.1, 10.2, 10.3, 10.4, 10.5, 10.6, 10.7, 10.8, 10.9, 11.0, 11.1, 11.2, 11.3, 11.4, 11.5, 11.6, 11.7, 11.8, 11.9, 12.0, 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 13.0, 13.1, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7, 13.8, 13.9, 14.0, 14.1, 14.2, 14.3, 14.4, 14.5, 14.6, 14.7, 14.8, 14.9, 15.0, 15.1, 15.2, 15.3, 15.4, 15.5, 15.6, 15.7, 15.8, 15.9, 16.0, 16.1, 16.2, 16.3, 16.4, 16.5, 16.6, 16.7, 16.8, 16.9, 17.0, 17.1, 17.2, 17.3, 17.4, 17.5, 17.6, 17.7, 17.8, 17.9, 18.0, 18.1, 18.2, 18.3, 18.4, 18.5, 18.6, 18.7, 18.8, 18.9, 19.0, 19.1, 19.2, 19.3, 19.4, 19.5, 19.6, 19.7, 19.8, 19.9, or 20.0 degrees) in a second direction with respect to the horizontal axis during generation of the photon (e.g., x-ray) beam. In some embodiments, the angular speed of rotation of the rocking motion is less than approximately 6 degrees per second (e.g., 1 to 6 degrees per second (e.g., 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4.0, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5.0, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, or 6.0 degrees per second)). In some embodiments, the beam delivery system comprises a slew drive bearing operatively engaged with the multileaf collimator, and the slew drive bearing alternately rotates the multileaf collimator to the first position and to the second position, e.g., to provide the rocking motion. FIG. 9A shows the multileaf collimator (150) at the 0-degree position within the nozzle housing (190), i.e., aligned with the horizontal axis. FIG. 9B shows the multileaf collimator (150) rotated 15 degrees in one direction within the nozzle housing (190). FIG. 9C shows a method for rocking the multileaf collimator comprising alternatingly rotating the multileaf collimator (150) from a first position (I) to a second position (II). As shown in FIG. 9C, rocking the multileaf collimator (150) between the first position (I) and the second position (II) comprises alternating rotations of 30 degrees between the first position (I) and the second position (II). In some embodiments, rocking the multileaf

collimator (150) comprises an initial rotation of 15 degrees from the 0-degree position to the first position (I) (FIG. 9C, top). In some embodiments, rocking the multileaf collimator (150) comprises a final rotation of 15 degrees from the second position (II) to the 0-degree position (FIG. 9C, bottom).

While FIG. 9C shows the first position (I) as a counterclockwise rotation from the 0-degree position and the second position (II) as a clockwise rotation from the 0-degree position, the first position (I) and the second position (II) are interchangeable such that the first position (I) may be a clockwise rotation from the 0-degree position and the second position (II) may be a counterclockwise rotation from the 0-degree position.

Further, while rocking the multileaf collimator is described in terms of 15-degree rotations with respect to the 0-degree position and 30-degree rotations between the first position and the second position, the technology is not limited to rotations of 15 degrees with respect to the 0-degree position and 30 degrees between the first position and the second position. Accordingly, the technology includes rotations of 10.0 to 20.0 degrees (e.g., 10.0, 10.1, 10.2, 10.3, 10.4, 10.5, 10.6, 10.7, 10.8, 10.9, 11.0, 11.1, 11.2, 11.3, 11.4, 11.5, 11.6, 11.7, 11.8, 11.9, 12.0, 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 13.0, 13.1, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7, 13.8, 13.9, 14.0, 14.1, 14.2, 14.3, 14.4, 14.5, 14.6, 14.7, 14.8, 14.9, 15.0, 15.1, 15.2, 15.3, 15.4, 15.5, 15.6, 15.7, 15.8, 15.9, 16.0, 16.1, 16.2, 16.3, 16.4, 16.5, 16.6, 16.7, 16.8, 16.9, 17.0, 17.1, 17.2, 17.3, 17.4, 17.5, 17.6, 17.7, 17.8, 17.9, 18.0, 18.1, 18.2, 18.3, 18.4, 18.5, 18.6, 18.7, 18.8, 18.9, 19.0, 19.1, 19.2, 19.3, 19.4, 19.5, 19.6, 19.7, 19.8, 19.9, or 20.0 degrees) from the 0-degree position to the first position or from the 0-degree position to the second position and includes alternating rotations of 20.0 to 40.0 degrees (e.g., 20.0, 20.1, 20.2, 20.3, 20.4, 20.5, 20.6, 20.7, 20.8, 20.9, 21.0, 21.1, 21.2, 21.3, 21.4, 21.5, 21.6, 21.7, 21.8, 21.9, 22.0, 22.1, 22.2, 22.3, 22.4, 22.5, 22.6, 22.7, 22.8, 22.9, 23.0, 23.1, 23.2, 23.3, 23.4, 23.5, 23.6, 23.7, 23.8, 23.9, 24.0, 24.1, 24.2, 24.3, 24.4, 24.5, 24.6, 24.7, 24.8, 24.9, 25.0, 25.1, 25.2, 25.3, 25.4, 25.5, 25.6, 25.7, 25.8, 25.9, 26.0, 26.1, 26.2, 26.3, 26.4, 26.5, 26.6, 26.7, 26.8, 26.9, 27.0, 27.1, 27.2, 27.3, 27.4, 27.5, 27.6, 27.7, 27.8, 27.9, 28.0, 28.1, 28.2, 28.3, 28.4, 28.5, 28.6, 28.7, 28.8, 28.9, 29.0, 29.1, 29.2, 29.3, 29.4, 29.5, 29.6, 29.7, 29.8, 29.9, 30.0, 30.1, 30.2, 30.3, 30.4, 30.5, 30.6, 30.7, 30.8, 30.9, 31.0, 31.1, 31.2, 31.3, 31.4, 31.5, 31.6, 31.7, 31.8, 31.9, 32.0, 32.1, 32.2, 32.3, 32.4, 32.5, 32.6, 32.7, 32.8, 32.9, 33.0, 33.1, 33.2, 33.3, 33.4, 33.5, 33.6, 33.7, 33.8, 33.9, 34.0, 34.1, 34.2, 34.3, 34.4, 34.5, 34.6, 34.7, 34.8, 34.9, 35.0, 35.1, 35.2, 35.3, 35.4, 35.5, 35.6, 35.7, 35.8, 35.9, 36.0, 36.1, 36.2, 36.3, 36.4, 36.5, 36.6, 36.7, 36.8, 36.9, 37.0, 37.1, 37.2, 37.3, 37.4, 37.5, 37.6, 37.7, 37.8, 37.9, 38.0, 38.1, 38.2, 38.3, 38.4, 38.5, 38.6, 38.7, 38.8,

38.9, 39.0, 39.1, 39.2, 39.3, 39.4, 39.5, 39.6, 39.7, 39.8, 39.9, or 40.0 degrees) between the first position and the second position during the rocking.

Tilted position

In some embodiments, the technology provides a method for treating a patient in a tilted position. As used herein, the term "tilted position" refers to a patient standing in a reclined position where the longitudinal axis of the standing patient is tilted at an angle of approximately 15 degrees, e.g., 10 to 20 degrees (e.g., 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25 degrees), with respect to a vertical Z axis of the photon radiation treatment system such that the patient head is located more posteriorly and the patient feet are position more anteriorly. A "tilted position" can be provided by rotating a patient (e.g., a patient supported on a patient rotation system (300)) through an angle ψ around an axis orthogonal to the Z axis (e.g., a horizontal axis such as an X axis) so that the head of the patient moves backward, and the feet of the patient move forward. See FIG. 10A. in some embodiments, the angle ψ is approximately 15 degrees, e.g., 10 to 20 degrees (e.g., 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25 degrees), with respect to a vertical Z axis of the photon radiation treatment system. A patient in a tilted position is more stable than a patient that is standing and not in a tilted position; thus, motion of the patient during treatment and imaging (e.g., for treatment planning or to verify or adjust patient position for treatment) is eliminated and/or minimized.

Accordingly, in some embodiments, the technology provides methods comprising providing a patient in a tilted position and contacting a treatment volume of the patient with a photon beam.

In some embodiments, methods for treating a patient in a tilted position comprise imaging a patient in a tilted position, e.g., using a medical imaging system as described herein comprising a gantry (220) and scanner ring (250), wherein the gantry is tilted at an angle such that the scanner ring can be translated to surround the patient (e.g., to position the treatment volume within the scanner ring bore) and acquire medical images of the treatment volume while the patient is in a tilted position. See FIG. 10B.

Accordingly, in some embodiments, methods comprise rotating a gantry comprising a scanner ring, providing a patient in a tilted position (e.g., by rotating a patient rotation system around an axis orthogonal to the Z axis), translating the scanner ring to an imaging position wherein the treatment volume of the patient is located within the bore of the

scanner ring, imaging the patient, translating the scanner ring to an overhead position, and treating the patient with a photon beam.

Rotational therapy

In some embodiments, the technology provides methods of rotational therapy. Methods of rotational therapy comprise contacting a patient with a photon (e.g., x-ray) beam while the patient is rotating around an axis of rotation of the patient. In some embodiments, methods of rotational therapy comprise contacting a patient with a photon (e.g., x-ray) beam while simultaneously: 1) rotating the patient around an axis of rotation of the patient; 2) rocking the multileaf collimator around the beam axis; and 3) moving the leaves of the multileaf collimator to modulate the beam shape. In some embodiments, methods of rotational therapy comprise contacting a patient with a photon (e.g., x-ray) beam while simultaneously: 1) rotating the patient around an axis of rotation of the patient; 2) rocking the multileaf collimator around the beam axis; 3) moving the leaves of the multileaf collimator to modulate the beam shape; and 4) translating the patient in a vertical direction, e.g., to provide a helical beam delivery.

In some embodiments, a patient in a tilted position is treated with rotational therapy. Thus, in some embodiments, methods of rotational therapy comprise providing a patient in a tilted position (e.g., by rotating the patient and/or patient rotation system around an axis orthogonal to the Z axis (e.g., an X axis)) and contacting the patient in a tilted position with a photon (e.g., x-ray) beam while the patient is rotating around an axis of rotation of the patient. In some embodiments, methods of rotational therapy comprise providing a patient in a tilted position (e.g., by rotating the patient and/or patient rotation system around an axis orthogonal to the Z axis (e.g., an X axis)) and contacting the patient in a tilted position with a photon (e.g., x-ray) beam while simultaneously: 1) rotating the patient around an axis of rotation of the patient; 2) rocking the multileaf collimator around the beam axis; and 3) moving the leaves of the multileaf collimator to modulate the beam shape. In some embodiments, methods of rotational therapy comprise providing a patient in a tilted position (e.g., by rotating the patient and/or patient rotation system around an axis orthogonal to the Z axis (e.g., an X axis)) and contacting a patient in a tilted position with a photon (e.g., x-ray) beam while simultaneously: 1) rotating the patient around an axis of rotation of the patient; 2) rocking the multileaf collimator around the beam axis; 3) moving

the leaves of the multileaf collimator to modulate the beam shape; and 4) translating the patient in a vertical direction, e.g., to provide a helical beam delivery.

In some embodiments of rotational therapy, the speed of rotation is constant. In some embodiments of rotational therapy, the speed of rotation is variable. In some embodiments of rotational therapy, the speed of translating the patient in the vertical direction is constant. In some embodiments of rotational therapy, the speed of translating the patient in the vertical direction is variable.

Although the disclosure herein refers to certain illustrated embodiments, it is to be understood that these embodiments are presented by way of example and not by way of limitation. All publications and patents mentioned in the above specification are herein incorporated by reference in their entirety for all purposes. Various modifications and variations of the described compositions, methods, and uses of the technology will be apparent to those skilled in the art without departing from the scope and spirit of the technology as described. Although the technology has been described in connection with specific exemplary embodiments, it should be understood that the invention as claimed should not be unduly limited to such specific embodiments. Indeed, various modifications of the described modes for carrying out the invention that are obvious to those skilled in the art are intended to be within the scope of the following claims.

CLAIMS

WE CLAIM:

1. A photon beam delivery system for use in a photon radiation treatment system, said photon beam delivery system comprising:
a photon generator configured to produce a beam of high-energy photons;
a collimator positioned between the photon generator and a patient;
a collimator housing positioned around the collimator, wherein the collimator is coupled to the collimator housing using an interference fit;
a multileaf collimator positioned between the collimator and the patient;
wherein, the photon beam passes through the collimator and multileaf collimator before reaching the patient.

2. The beam delivery system of claim 1, wherein the photon generator includes a waveguide and a waveguide shield positioned around the waveguide.

3. The beam delivery system of claim 2, wherein the waveguide shield is coupled to a rail configured to allow the waveguide shield to move between a first position and a second position,
wherein the waveguide shield is positioned around the waveguide in the first position and the waveguide shield is positioned at a distance away from the waveguide in the second position.

4. The beam delivery system of claim 1, further comprising:
an adjustment ring coupled to the photon generator; and
a mounting plate abutting the adjustment ring,
wherein the adjustment ring and mounting plate are configured to adjust the orientation of the photon generator relative to the collimator.

5. The beam delivery system of claim 4, wherein the adjustment ring and mounting plate make contact along a substantially spherical surface.

6. The beam delivery system of claim 1, wherein the beam delivery system comprises a nozzle housing comprising an indentation, wherein the indentation is sized and configured to prevent collision of the beam delivery system, the patient, and the photon radiation treatment system during operation.

7. The beam delivery system of claim 6, wherein the beam delivery system comprises a nozzle configured to move between a treatment position and a storage position.

8. The beam delivery system of claim 7, further comprising a shutter, wherein the shutter is configured to be in a lowered position when the nozzle is in the treatment position and the shutter is configured to be in a raised position when the nozzle is in the storage position.

9. The beam delivery system of claim 1, wherein the multileaf collimator is configured to rotate around a beam axis alternately clockwise and counterclockwise between a first position and a second position while the beam delivery system provides the beam of high-energy photons.

10. The beam delivery system of claim 9, wherein the multileaf collimator rotates approximately 5 to 45 degrees between the first position and the second position.

11. The beam delivery system of claim 9, wherein the multileaf collimator rotates approximately 5 to 25 degrees to the first position or to the second position.

12. The beam delivery system of claim 9, wherein the multileaf collimator rotates approximately 30 degrees between the first position and the second position.

13. The beam delivery system of claim 9, wherein the multileaf collimator rotates approximately 15 degrees from a 0-position to the first position or to the second position.

14. The beam delivery system of claim 9, wherein the multileaf collimator rotates between the first position and the second position while a patient is rotated around a patient axis of rotation.

15. The beam delivery system of claim 9, wherein the multileaf collimator rotates between the first position and the second position while a number of leaves of the multileaf collimator are translated.

16. A photon radiation treatment system comprising a beam delivery system, a medical imaging system, and a patient rotation system.

17. The photon radiation treatment system of claim 16, wherein the beam delivery system is the beam delivery system of claim 1.

18. The photon radiation treatment system of claim 16, wherein the medical imaging system comprises a scanner ring configured to move between an overhead position and an imaging position, and wherein the beam delivery system is configured to move between a treatment position and a storage position.

19. The photon radiation treatment system of claim 18, wherein the scanner ring is in the overhead position when the beam delivery system is in the treatment position and the scanner ring is in the imaging position when the beam delivery system is in the storage position.

20. The photon radiation treatment system of claim 18, wherein movement of the scanner ring between the overhead position and the imaging position is coordinated with movement of the beam delivery system between the treatment position and the storage position.

21. The photon radiation treatment system of claim 16, wherein the patient rotation system is configured to support a patient in an upright position for imaging and treatment.

22. The photon radiation treatment system of claim 16, wherein the medical imaging system comprises:

a first scanner pillar and a second scanner pillar;

a gantry rotatably coupled to the first scanner pillar and the second scanner pillar; and

a scanner ring translatably coupled to the gantry, wherein the scanner ring comprises a photon source and a photon detector on opposite sides of a bore surrounded by the scanner ring.

23. The photon radiation treatment system of claim 22, wherein the patient rotation system is configured to support a patient in a tilted position.

24. The photon radiation treatment system of claim 23, further comprising a patient supported in a tilted position.

25. The photon radiation treatment system of claim 24, wherein the gantry is rotated around a horizontal axis for imaging the patient in a tilted position.

26. The photon radiation treatment system of claim 24, wherein the patient supported in a tilted position is contacted with photon radiation produced by the beam generation system.

27. The photon radiation treatment system of claim 16, wherein the medical imaging system is provided in a rotated orientation such that an angle of approximately 110 to 135 degrees is formed between the beam axis and the major axis of the scanner bridge.

28. The photon radiation treatment system of claim 27, wherein the rotated orientation of the medical imaging system provides an increased ingress/egress area relative to the medical imaging system in an unrotated orientation.

29. A method of treating a patient, said method comprising:

providing a photon radiation treatment system comprising a beam delivery system, a medical imaging system, and a patient rotation system;
positioning a patient on the patient rotation system in an upright position;
imaging the patent on the patient rotation system in the upright position;
producing a photon beam by the beam delivery system; and
contacting the patient in the upright position with the photon beam.

30. The method of claim 29, further comprising rotating the patient rotation system and the patient while contacting the patient with the photon beam.

31. The method of claim 29, further comprising rotating a multileaf collimator around a beam axis alternately between a first position and a second position while contacting the patient with the photon beam.

32. The method of claim 31, wherein the first position and the second position are approximately 5 to 45 degrees apart.

33. The method of claim 31, wherein the first position and the second position are approximately 30 degrees apart.

34. The method of claim 29, further comprising translating the patient in a vertical direction while contacting the patient with the photon beam.

35. The method of claim 29, further comprising translating a number of leaves of a multileaf collimator while contacting the patient with the photon beam.

36. The method of claim 29, wherein the upright position is a tilted position locating the patient head posteriorly and the patient feet anteriorly.

37. A method of treating a patient, said method comprising:
providing a photon radiation treatment system comprising a beam delivery system, a medical imaging system, and a patient rotation system;
positioning a patient on the patient rotation system in an upright position;

imaging the patent on the patient rotation system in an upright position;
producing a photon beam by the beam delivery system; and
contacting the patient in the upright position with the photon beam while simultaneously:

a) rotating the patient rotation system and the patient;
b) rotating a multileaf collimator around a beam axis alternately between a first position and a second position;
c) translating the patient in a vertical direction; and
d) translating a number of leaves of a multileaf collimator.

38 The method of claim 37, wherein the first position and the second position are approximately 5 to 45 degrees apart.

39. The method of claim 37, wherein the first position and the second position are approximately 30 degrees apart.

40. The method of claim 37, wherein imaging the patient provides medical images of the patient for planning treatment, verifying a patient position, or adjusting a patient position.

41. The method of claim 37, wherein the patient has a cancer.

42. A method of treating a patient, said method comprising:
providing a medical imaging system comprising a scanner ring in an overhead position;
providing a beam delivery system in a storage position;
positioning a patient on a patient rotation system in an upright position;
translating the scanner ring to an imaging position in which the patient is located within a bore of the scanner ring;
imaging the patient;
translating the scanner ring to the overhead position;
translating the beam delivery system to a treatment position;

contacting the patient with a photon beam produced by the beam delivery system; and

translating the beam delivery system to the storage position.

43. The method of claim 42, further comprising rotating the patient rotation system and the patient while contacting the patient with the photon beam.

44. The method of claim 42, wherein imaging the patient provides medical images of the patient for planning treatment, verifying a patient position, or adjusting a patient position.

45. The method of claim 42, wherein the patient has a cancer.

46. The method of claim 42, wherein the beam delivery system comprises a nozzle housing and the nozzle housing comprises an indentation to provide clearance for rotation of the patient rotation system and/or the patient when the beam delivery system is in the treatment position.

47. The method of claim 46, wherein the beam delivery system in the storage position provides the nozzle housing in a position that locates a surface of the nozzle housing to be flush with a wall.

48. The method of claim 47, wherein the beam delivery system further comprises a shutter that covers a void in the wall when the beam delivery system is in the storage position.

49. A method of treating a patient, said method comprising:

providing a photon radiation treatment system comprising a beam delivery system and a patient rotation system;

positioning a patient on the patient rotation system in a tilted position, wherein the patient comprises a head and feet; and

contacting the patient with photon radiation produced by the beam delivery system while the patient is in the tilted position.

50 The method of claim 49, wherein positioning a patient on the patient rotation system in a tilted position comprises positioning the patient in an upright position on the patient rotation system and rotating the patient rotation system and the patient around a horizontal axis so that the head of the patient moves posteriorly and the feet of the patient move anteriorly.

51. The method of claim 49, wherein the patient in the tilted position is tilted approximately 15 degrees with respect to a Z axis.