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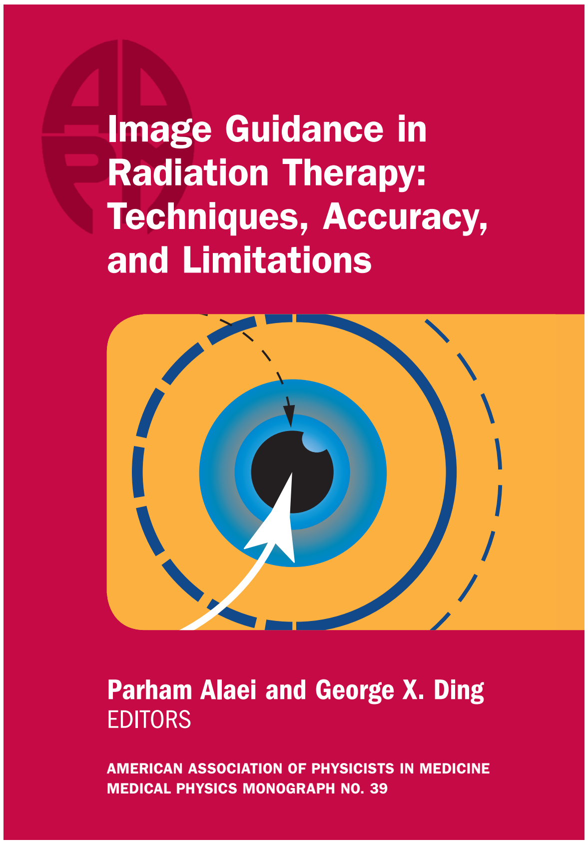

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Chapter 1

Overview of Image Guidance in Radiation Therapy

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1.1 Historical Perspectives

The use of x-rays in medical diagnosis and treatment began shortly after their discovery by Röentgen in 1895. Since then, radiotherapy has developed into an important cancer treatment specialty. The success of radiation therapy requires that radiation is aimed at the target, while avoiding the healthy tissue. In the early days of radiation therapy, patients were positioned relative to a radiation source visually. As radiation was primarily (but not exclusively) used for skin lesions, this was sufficient. As delivery units capable of delivering higher-energy beams that could penetrate deeper body tissues were developed, the need for proper patient localization with respect to the radiation beam grew.

Prior to the development of Co-60 units, orthovoltage x-ray generators were the common devices used for radiation therapy. The x-rays used to treat the patient were occasionally used for imaging as well. For example, Nielsen and Jensen reported in

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1942 on the use of a fluoroscopic screen that captured images produced by a 180 kVp x-ray beam of a rotation therapy unit (Nielsen and Jensen 1942). The observer, sitting outside the treatment room behind leaded glass watched the image on the fluoroscopic screen and adjusted the beam remotely if needed. This may have been the first image-guided radiation therapy system. Similarly, an "image-guided rotation therapy" unit designed at the Netherlands Cancer Institute (NKI) in 1950 made use of the transmitted x-ray beam incident on a fluorescent screen and observed by a radiologist via a mirror for image guidance of patient treatment (Figure 1–1). The radiologist was able to adjust the field size and position of the beam using remote control.

A similar device (television-controlled pendulum therapy) described by Wallman (Wallman and Stålberg 1958) and Strandqvist (Strandqvist and Rosengren 1958) used fluorescent screen and image intensifier to produce the images captured by a camera and displayed on a video monitor (Figure 1–2) This system was capable of remote translational movement of the patient couch based on the image displayed on the monitor. These images suffered from low contrast and limited field of view.

Similar fluorescence-based devices were employed with megavoltage beams. For example, Andrews et al. (1958) reported on "continuous visual monitoring" of 2 MV x-rays produced by a Van De Graaff accelerator, similar to the technique described by Wallman and Strandqvist for orthovoltage beam. Due to low contrast of the images, very low- or high-density materials, air and mercury, were used as contrast agents.

Figure 1–1 Image-guided rotation therapy installed at NKI circa 1950 (https://www.historad.com/en/#!/en/100-years-radiotherapy-netherlands-cancer-institute-rebuilding/image-guided-rotational-therapy/).

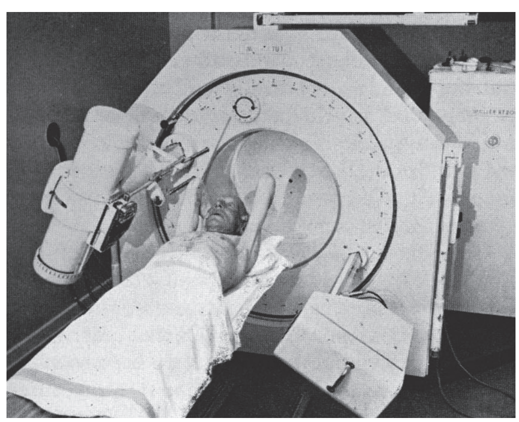

Figure 1–2 Television-controlled pendulum therapy. From Strandqvist and Rosengren (1958) with permission

Benner et al. (1962) employed the same system with 30 MV x-rays and used heavy metals as contrast agents.

The use of radiographic film with megavoltage beams was a common positioning verification tool dating back to the second half of the 20th century. For example, several groups reported on the use of radiographic films exposed with Co-60 radiation for patient positioning during rotation therapy (Pfalzner and Inch 1956; Perryman, McAllister, and Burwell 1960; Springer et al. 1962). Swain and Steckel (1966) reported the first use of film with 2 MV x-rays.

The value of frequent verification films to ensure proper patient positioning was realized in the early days of radiation therapy, and their role in error detection and prevention was reported by many (Haus, Pinsky, and Marks 1970; Marks et al. 1976 and 1974; Byhardt et al. 1978).

To overcome the poor quality of the film exposed to megavoltage beams, there have been many attempts to incorporate diagnostic quality imaging in radiation therapy delivery devices dating back to the 1950s. These include:

- mounting of a portable x-ray tube on the counterweight of a Co-60 unit (Holloway 1958),
- the addition of an x-ray tube to the head of a Co-60 unit above the source (Johns and Cunningham 1959),
- the addition of a retractable x-ray tube to a linear accelerator (Weissbluth et al. 1959),
- the addition of an x-ray tube at 90 degrees to the Co-60 beamline (NKI, Amsterdam 1961), and
- the addition of a "high kV" x-ray tube to the head of a Co-60 unit at an angle (Shorvon, Robson, and Day 1966).

For example, the addition of an x-ray tube to the counterweight of a Theratron Co-60 unit at the Ontario Cancer Foundation (Holloway 1958) provided a radiograph of the patient after rotating the unit by 135 degrees, placing the x-ray tube at zero degree (upright) position (Figure 1–3).

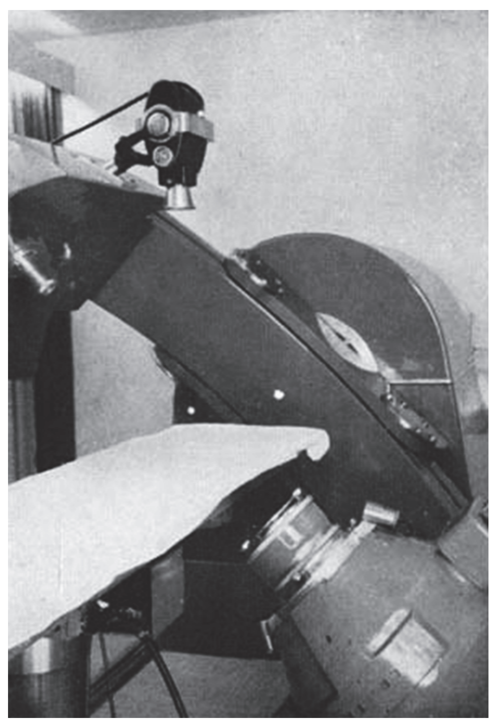

Figure 1–3 X-ray tube mounted on the counter weight of a Co-60 unit. From Holloway (1958) with permission

The Johns and Cunningham addition of diagnostic-quality x-rays to a cobalt unit above the source did not require the rotation of the unit, but resulted in slightly smaller beam's-eye view (BEV) than the therapeutic beam (Johns and Cunningham 1959). On the other hand, the Stanford linear accelerator design (Weissbluth et al. 1959) placed the x-ray tube closer to the patient than the megavoltage source, hence slightly larger BEV than the therapeutic beam one. This design allowed for dual-energy radiography of the treatment portal by first imaging using the x-ray tube, retracting it, and then imaging with the megavoltage beam (Figure 1–4).

The NKI design mounted the cobalt unit, x-ray tube, and x-ray image intensifier on a steel ring, producing an orthogonal, isocentric design (Figure 1–5). This design

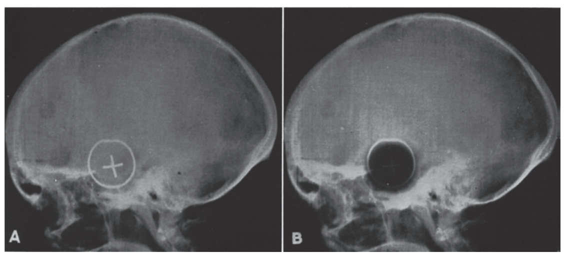

Figure 1–4 A) kV radiograph and B) kV radiograph with the addition of MV imaging. From Weissbluth et al. (1959) with permission.

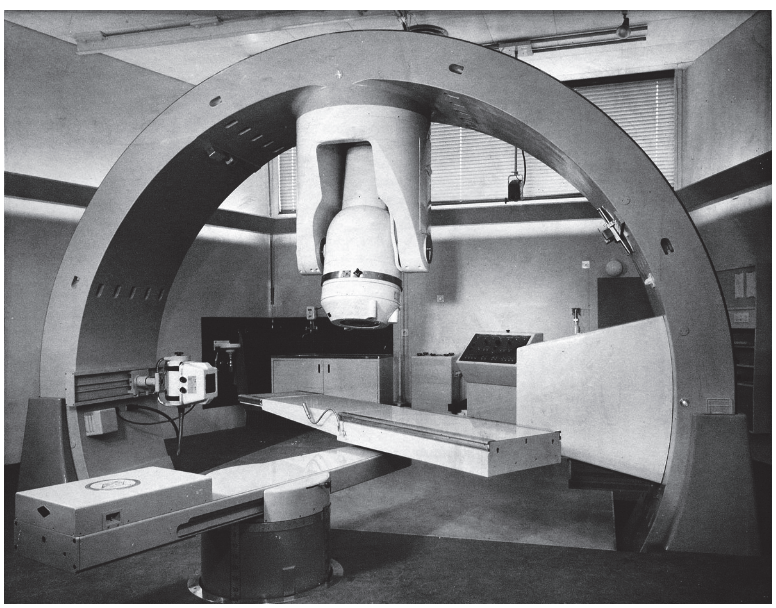

Figure 1–5 Image-guided cobalt unit installed at NKI circa 1960 (https://www.historad.com/en/#!/e4n/100-years-radiotherapy-netherlands-cancer-institute-rebuilding/image-guided-cobalt-unit-introduced-in-the-nki/).

in analogous to today's gantry-mounted cone-beam CT (CBCT) systems. Finally, Shovron added an x-ray tube to the head of a cobalt-60 Mobaltron unit at an angle of 44 degrees, hence imaging the treatment area by rotating the gantry by that amount.

Following these early attempts in integrating therapeutic and diagnostic beams, there was limited progress made in this area until the 1980s when Biggs et al. (1985) and Shiu et al. (1987) added an offset gantry-mounted x-ray tube to a linear accelerator and cobalt-60 unit, respectively. Biggs' design had a therapy beam/diagnostic beam angle of 45 degrees. Shiu's design had a 50-degree angle between imaging and therapy beams, and by rotating the gantry, double-exposed images were produced, combining kV and Co-60 beams. A similarly designed system was proposed by Sephton and Hagekyriakou (1995).

Parallel to these developments in imaging for x-ray therapy, daily imaging using kilovoltage x-rays was commonly used in proton, neutron, and heavy charged particle therapy facilities (Tobias et al. 1958; Saunders et al. 1985). The role of imaging in proton therapy is discussed in detail in chapter 7.

1.2 Two-dimensional X-ray Imaging

1.2.1 Radiographic Film

Although it is difficult to determine when imaging as a verification method for field placement was first used (Jaffrey et al. 2005), it is safe to assume that radiographic film was the first tool used to ensure accurate geometric placement of treatment portal in radiation therapy by capturing an image of the portal, the process commonly referred to as portal imaging. This coincided with the development of radiation therapy delivery units capable of producing beams in the megavoltage energy range. As stated by Munro (1999), because of the need for accurate geometric placement of the beams, much effort has been devoted to the development of convenient methods to check patient positioning.

The first uses of radiographic film for imaging during radiation therapy with therapeutic megavoltage beams (including Co-60) were documented in the 1950s and 60s (Hare et al. 1951; Perryman, McAllister, and Burwell 1960; Deans 1962, Springer et al. 1962; Swain and Steckel 1966). In its 1962 paper, Deans describes megavoltage radiography as "all washed-up, a poor wishy-washy radiograph, but one perhaps not entirely without honour...." Therefore, efforts were focused on optimizing the images created from megavoltage beams.

Hare et al. (1951) used radiographic film with 2 MV x-rays and reported good visualization of the air passages and faint contrast between bone and soft tissue. They subsequently injected air to delineate the bladder and rectum. They also utilized a double-exposure technique to visualize anatomy surrounding the treatment field. Perryman et al. (1960) used three types of film inside cassettes, but replaced intensifying screens with lead sheets to reduce the number of low-energy electrons and produce high-energy electrons. Springer et al. (1962) interposed fluorescent screens between lead sheets in order to decrease the exposure time and increase the contrast. And finally, Swain et al. (1966) used a low-sensitivity film to image patients throughout the duration of radiation therapy, which deferred from the commonly employed process of moving the patient between film exposure and treatment. Further efforts led to the introduction of a film, later known as XV2, for therapy verification purposes (Munro 1999). This film was compatible with the 90-second film processors introduced to the hospitals in 1965 (Haus 1993).

The use of film for patient positioning and even patient dosimetry was further refined by Haus (Haus, Pinsky, and Marks 1970; Haus, Strubler, and Marks 1972; Haus, Marks, and Griem 1973; Haus and Marks 1973). The role of imaging using film as part of the overall scheme of minimizing localization errors of patients undergoing radiation therapy was further stressed by Marks and others (Marks et al. 1974 and 1976; Marks and Haus 1976; Verhey et al. 1982; Rabinowitz et al. 1985).

With the wide availability of electronic portal imaging devices and the decreased production of radiographic films due to lack of demand, the use of radiographic film for patient position verification has effectively come to an end.

1.2.2 Electronic Portal Imaging Devices

Imaging without relying on radiographic film was proposed as early as the 1950s. (Strandqvist and Rosengren 1958; Wallman and Stålberg 1958; Andrews, Swain, and Rubin 1958; Benner et al. 1962; Baily, Horn, and Kampp 1980; Meertens, Van Herk, and Weeda 1985; Leong 1986; van Herk and Meertens 1988; Ezz et al. 1992). This gave rise to the development of electronic portal imaging devices (EPIDs). There have been several reviews on the evolution of electronic portal imaging devices (Boyer and Meertens 1992; Munro 1995; Antonuk 2002).

The camera-mirror-lens-based EPID systems were the first to be developed and commercialized starting in the late 1980s (Antonuk 2002). A few examples of these systems are shown in Figure 1–6. These devices consist of a metal plate which acts as the source of high-energy electrons and a fluorescent screen which converts them into light, which is then projected into a camera after reflection by a mirror placed at a 45° angle.

Parallel to the camera-based systems, the scanning matrix ionization chamber system developed at NKI was commercialized in 1990 (Meertens, Van Herk, and Weeda 1985; van Herk and Meertens 1988). These devices consist of two sets of electrodes perpendicular to each other with their gap filled with a fluid that is ionized by radiation. One set of electrodes is connected to an electrometer and the other to a high-voltage power supply. For obtaining one image, the ionization matrix is scanned row by row, by successively switching high voltage to different row electrodes, and measuring the current in column ones. Since this is a scanning EPID, it is more susceptible to artifacts caused by changes in dose rate (van Herk and Meertens 1988; Munro 1999). The major advantage of these systems over the camera-mirror-lens-based ones is their compactness.

The active matrix flat panel imager (AMFPI) systems were developed in the 1980s and 90s and were commercialized in 2000 (Street et al. 1990; Antonuk et al. 1990). These devices consist of amorphous silicon or amorphous selenium arrays. The majority of currently used EIPDs are AMFPI systems. These systems are described in detail in chapter 2.

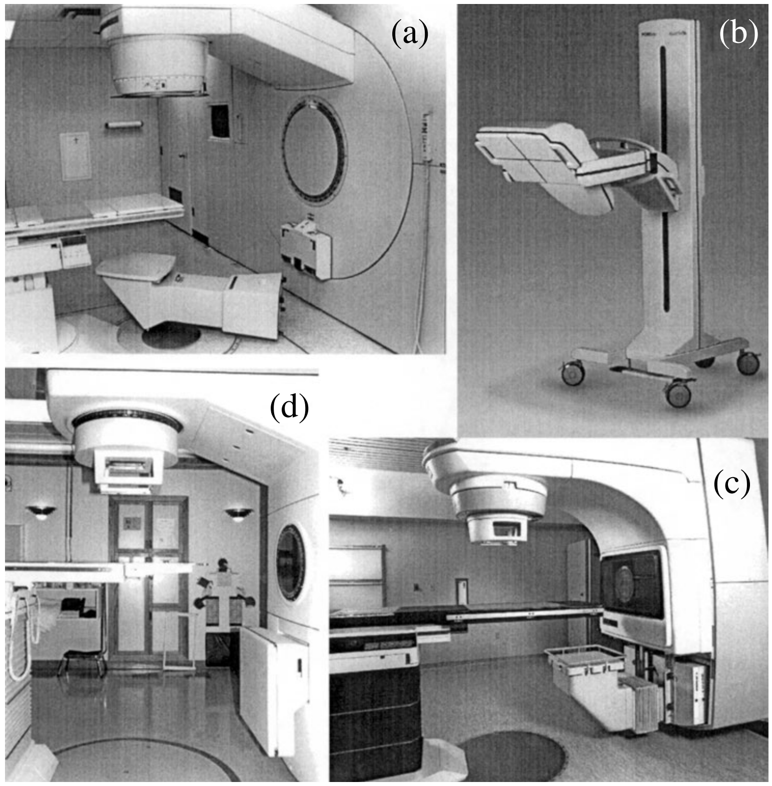

Figure 1–6 TV-camera-based EPIDs. (a) the Elekta iView, (b) the Eliav PORTpro, (c) the Infimed Theraview, and (d) the Siemens Beamview plus. From Munro (1999) with permission.

The advantages of current digital imaging systems include real-time imaging, feasibility of post-processing the images, digital storage, and automatic matching with the digitally reconstructed radiographs (DRRs). In addition to pretreatment imaging, portal imaging devices have been used in the fluoroscopy mode for real-time patient imaging and position adjustment (De Neve et al. 1992).

1.2.3 Room-mounted kV Imaging Systems

Room-mounted x-ray imaging systems were first developed in the 1990s (Murphy and Cox 1996; Schewe et al. 1998; Adler Jr. et al. 1999; Shirato, Shimizu, Kunieda, et al. 2000; Yin et al. 2002). These devices have been used for patient imaging prior to and during delivery of radiation, including using fluoroscopic imaging for real-time tumor tracking (Shirato, Shimizu, Kitamura, et al. 2000; Shirato, Shimizu, Kunieda, et al. 2000). Some of these systems were introduced as part of image-guided frameless radiosurgery systems, including Accuray's CyberKnife (Accuray, Inc., Sunnyvale, CA) and BrainLab Novalis/ExacTrac (Brainlab AG, Munich, Germany) (see Figure 1–7). The room-mounted systems typically consist of a pair of x-ray tube/ imaging panels mounted in the floor and on the ceiling orthogonal to each other. These systems are capable of rapid imaging of the patient during radiation therapy delivery, which is utilized for real-time stereoscopic imaging and patient position adjustments using bony anatomy or implanted fiducial markers. This is typically achieved in combination with 6 degree-of-freedom (6 DOF) couch and infrared tracking systems. The simultaneous acquisition of two orthogonal radiographs is not limited by the treatment table angles with these room-mounted systems. There is further description of these systems and their imaging panels in chapter 2.

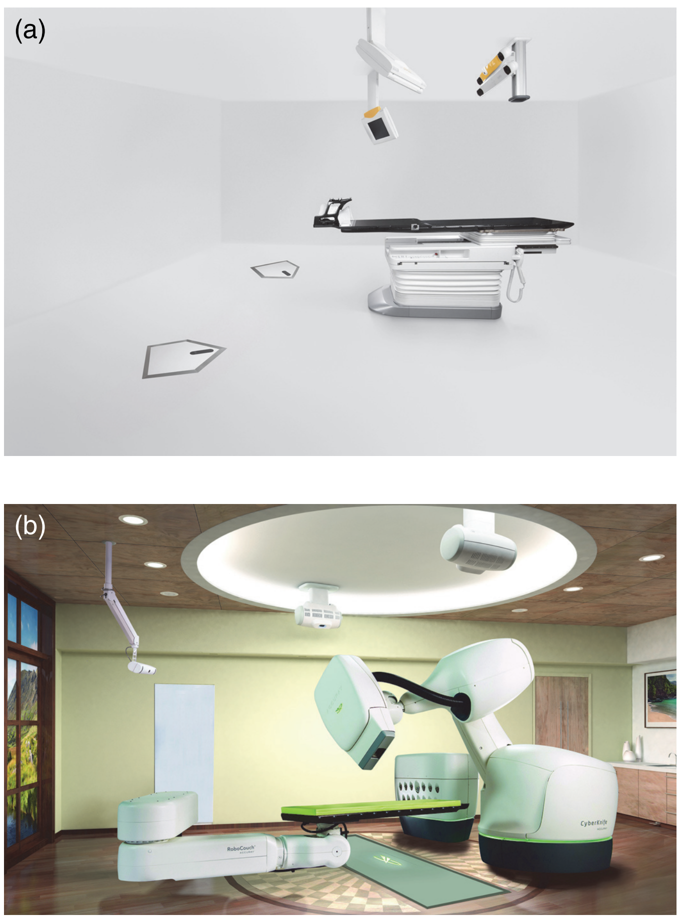

Figure 1–7 (a) The BrainLab System with imaging tubes in the floor and imaging panels mounted on the ceiling. (b) Accuray CyberKnife system with kV imaging tubes mounted on the ceiling and imaging panels in the floor. (Courtesy of Accuray, Inc. and BrainlabAG.)

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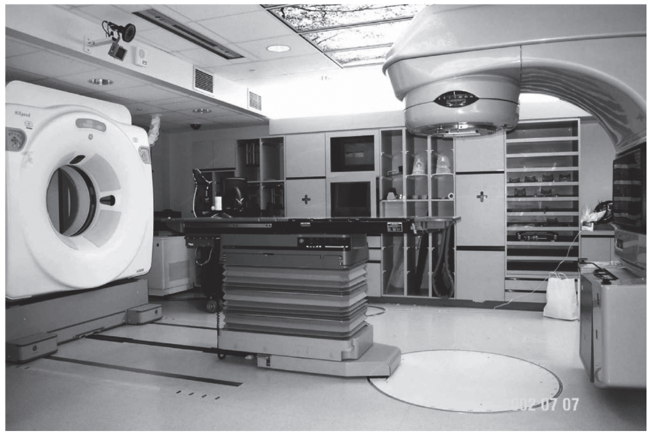

Figure 1–8 A combined CT-linac system. From Court et al. (2003) with permission.

1.3 Three-dimensional X-ray Imaging

1.3.1 Combined CT/Linac

One method to obtain quality CT images at the treatment time is to install a conventional CT scanner in a linear accelerator room, which was proposed in the 1990s (Uematsu et al. 1996; Uematsu et al. 1998; Jaffray et al. 1999; Kuriyama et al. 2003; Court et al. 2003). These systems are generally designed such that the linac and CT share a gantry axis and are positioned at the opposite ends of the couch. The CT is on rails and can slide over the patient for scanning. The couch is then rotated 180 degrees, placing the patient at gantry isocenter (Figure 1–8). Due to the movement of the couch, there is the potential of added uncertainties in these systems. However, Court et al. (2003) evaluated these uncertainties and concluded that the total daily setup variation was less than 0.7 mm in any of the three orthogonal directions. Further description of these systems can be found in chapter 4.

1.3.2 Megavoltage CT/CBCT

1.3.2.1 Megavoltage CT

Instead of using diagnostic energy x-rays, Simpson et al. (1982) mounted an array of detectors to a frame bolted to the counterweight of a 4 MV linear accelerator to create the first reported MV CT images. Brahme similarly utilized a detector array for MV CT scanning using a 50 MV beam from a microtron (Brahme, Lind, and Näfstadius 1987). Both of these acted as a “third generation” CT scanner. Nakagawa et al. (1992) developed a similar system using a 6 MV beam. The development of kV cone-beam CT systems ended further developmental work on obtaining MV CT images from a C-arm linac.

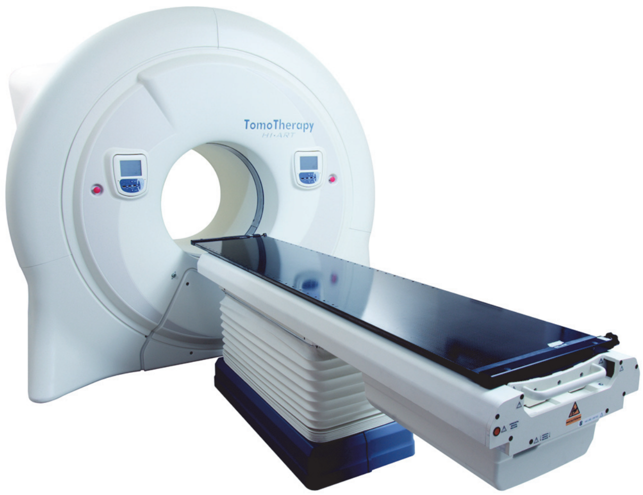

Figure 1–9 The TomoTherapy Hi-Art radiation therapy delivery system. (Image courtesy of Accuray, Inc.)

The only current radiation therapy delivery system employing MV CT is the Accuray TomoTherapy (now Radixact) system (Figure 1–9). The initial TomoTherapy system design, first proposed in 1993, included a kV CT unit (Mackie and Swerdloff 1993). However, once it was determined that high-quality images could be obtained with a megavoltage beam, the kV CT component was dropped in favor of MV CT (Mackie 2006). The CT images in this system are generated using a 3.5 MV beam. The future plans for Radixact units include the addition of kV CBCT capabilities. Megavoltage CT is described in detail in chapter 8.

1.3.2.2 Megavoltage Cone-beam CT

Using the portal imagers to perform megavoltage cone-beam computed tomography was explored in the 1990s, and a prototype system using the 6 MV beam of a Philips SL-25 linear accelerator was proposed in 1998 (Mosleh-Shirazi et al. 1998). This concept was further developed (Pouliot et al. 2005; Morin et al. 2006) and commercialized by Siemens (Erlangen, Germany). A further development on the evolution of MV CBCT was the use of 4.2 MeV electrons impinged on a carbon target to achieve a lower-dose imaging beam providing better soft tissue contrast (Faddegon et al. 2008). This imaging beam was named imaging beamline (IBL) to distinguish it from the 6 MV therapy beamline (TBL).

The use of megavoltage CBCT has been on the decline due to the lack of continued development by the manufacturers and Siemens' discontinuation of linear accelerator production. However, the recently introduced Halcyon system (Varian Medical Systems, Palo Alto, CA) (Figure 1–10) has MV CBCT capabilities using the same

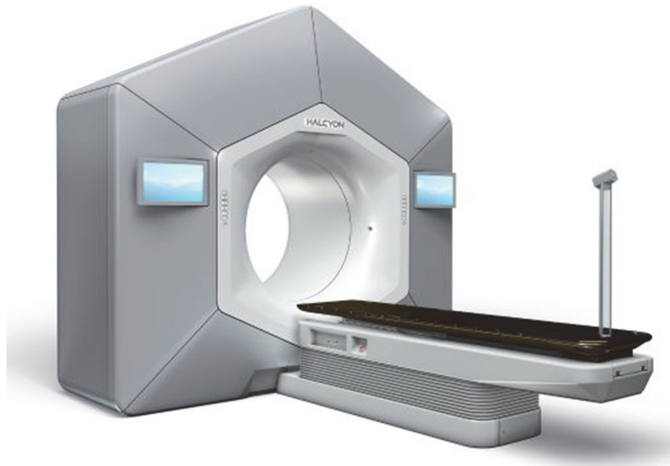

Figure 1–10 The Halcyon radiation therapy delivery system. (Image courtesy of Varian Medical Systems.)

6 MV flattening filter free beam used for treatment. This system is also capable of MV portal imaging. Both imaging modalities on the Halcyon operate in low-dose and high-quality (hence, higher dose) modes (Li et al. 2018). Megavoltage CBCT systems are described in detail in chapter 8.

1.3.3 Gantry-mounted kV Imaging and kV CBCT

Although the idea of attaching a kV imaging system to the therapy equipment gantry dates back to the 1950s, it only matured in the late 1990s with the addition of kV x-ray tubes/image receptors orthogonal to the MV therapy beam (Cho, Johnson, and Griffin 1995; Jaffray et al. 1999; Jaffray and Siewerdsen 2000; Jaffray et al. 2002). Kilovoltage cone-beam CT (kV CBCT) has now become standard equipment on linear accelerators made by Elekta (Elekta Instruments, Stockholm, Sweden) and Varian. The BrainLab/Mitsubishi Vero system (acquired by Hitachi, Tokyo, Japan) radiation delivery system also includes kV x-ray tube/imaging panels (Kamino et al. 2006). In another system developed by Fast et al. (2012), kV x-ray tube and image receptors were mounted antiparallel to the megavoltage beamline on a Siemens Artiste linac. This system was commercialized by Siemens under the name "kVision." Figure 1–11 shows commonly used gantry-mounted kV CBCT systems.

Gantry-based kV CBCT systems are described in detail in chapter 8. In addition to the Varian and Elekta systems, the Accuray Radixact and the newly introduced Varian Halcyon system will also have kV x-ray capabilities in the future.

With the progress in the field of frameless radiosurgery, systems that traditionally relied on fixed frames are implementing kV imaging capabilities. The Elekta Gamma Knife Icon (Figure 1–12), utilizes kV CBCT, with the kV image source/receptor attached to it independent of the radiation delivery system. Also, the radiosurgery unit being developed by Zap Surgical Systems (San Carlos, CA) is anticipated to have kV CBCT imaging capabilities in the future.

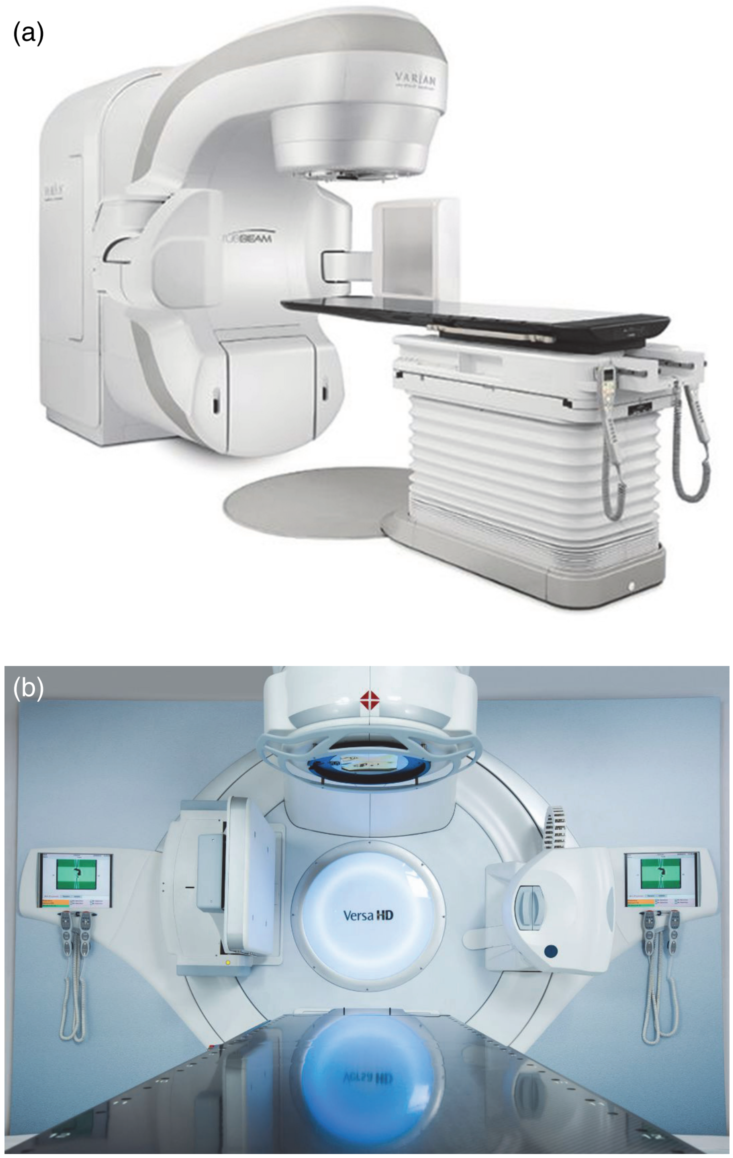

Figure 1–11 (a) The Varian TrueBeam and (b) the Elekta Versa HD linear accelerators with additional kV x-ray tube/imaging panels. (Images courtesy of Varian Medical Systems and Elekta Instrument AB.)

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Figure 1–12 The Leksell Gamma Knife Icon with kV CBCT arm in retracted position. (Image courtesy of Elekta Instrument AB.)

1.3.4 Combined kV/MV Imaging

Following earlier efforts by Biggs et al. (1985) and Shiu et al. (1987) in the 1980s, Jaffray et al. (1995) investigated dual beam/energy imaging by mounting an x-ray tube on the gantry of a linear accelerator at 45 degrees. Furthermore, Cho and Munro (2002) proposed the design of a target assembly that would include a kilovoltage target. Alongside these efforts, Galbraith (1989), Mah (1993), and Ostapiak et al. (1998) proposed using low-Z targets with high-energy beams to achieve low-energy imaging.

Pisani et al. (2000) proposed online correction of setup errors using both kV and MV radiographs. An advantage of imaging patients using both MV and kV beams is to get the best of both worlds: MV's reduced sensitivity to metal artifacts and kV's advantage of higher soft tissue contrast. Li et al. developed a technique to generate virtual monochromatic CBCT from kV/MV projections to optimize the image contrast while minimizing the artifacts (Li, Liu, and Yin 2013). And Zhang et al. (2017) developed a method to reconstruct 4D CBCT images using limited-angle kV and MV imaging for intrafraction verification.

Combined kV/MV imaging is currently in the research and development stage. Chapter 5 discusses combined kV/MV imaging and tomosynthesis in detail.

1.4 Non X-ray Imaging

1.4.4 Ultrasound Guidance

The initial implementation of ultrasound for radiation therapy positioning involved using a 2D ultrasound system for prostate radiation therapy (Lattanzi et al. 2000; Mohan, Kupelian, and Willoughby 2000). The system consisted of a B-mode transabdominal ultrasound probe attached to a precision tracking arm (BAT system, Best nomos, Inc., Pittsburgh, PA). Daily ultrasound positioning of the patient is achieved by importing isocenter and contour data from treatment planning system into the ultrasound system. The therapist then positions the ultrasound probe on the patient's abdomen and acquires axial and sagittal images. Patient contours are superimposed on the ultrasound images, and the patient can be moved such that the prostate is positioned relative to the treatment beam in the same location as the treatment plan.

Future developments included adding optical tracking to the ultrasound imaging, allowing 3D acquisition of ultrasound data (Chinnaiyan et al. 2003). Newer systems such as the Elekta Clarity employ 4D monitoring using a remotely operated ultrasound probe. A detailed description of ultrasound-guided radiation therapy is given in chapter 6.

1.4.5 Electromagnetic Transponders

The use of implanted electromagnetic transponders (beacons) for patient positioning was first proposed by Balter et al. (2005). The beacons are implanted in the same fashion as inactive (gold) markers are implanted for visualization using electronic portal imaging. This system was further commercialized by Calypso Medical Systems, now part of Varian. The system consists of a number of wireless transponders implanted in the patient and a magnetic source and receiver coil array to detect their position. The transponders are implanted in the patient, usually in prostate or soft tissue tumors, and are approximately 8 mm in length and 2 mm in diameter. A panel containing source and receiver coils is positioned above the patient. The source coil produces an electromagnetic field which induces a resonance inside the transponders. The decay of the resonant signal is then detected by the receiver coil. Use of multiple transponders with different resonant frequencies allows for localization of each transponder. The panel's location within the treatment room is determined using ceiling-mounted infrared cameras and infrared markers on the panel (Willoughby et al. 2012).

Limitations of these devices include the potential migration of the transponders, limited operating range, and needed setup time prior to each treatment. In addition, the panel should be removed after localization and prior to treatment to avoid collision, and it cannot be used at the same time as portal imaging or cone-beam CT. Figure 1–13 shows the Calypso system.

A similar system, RayPilot (Micropos Medical, Gothenburg, Sweden), utilizes a wired transmitter which is inserted into an implanted catheter in the prostate or lung. The receiver is a sensor plate placed on an existing treatment table. This precludes the use of a panel similar to Calypso system, hence avoiding some of the issues raised above, such as collision and inability of concurrent x-ray imaging.

Figure 1–13 The Calpyso System. (Image courtesy of Varian Medical Systems.)

1.4.6 MR Guidance

MR guidance in radiation therapy has been under development for many years, and the first commercial systems used a 0.3 Tesla magnet in combination with three Co-60 sources (ViewRay, Inc., Oakwood Village, OH), which has demonstrated its ability to observe organ movement in real time during the radiation delivery. Overcoming the technical difficulties of combining a linear accelerator with an MRI, there are currently two commercial MR-linac systems: MRIdian by ViewRay and Unity by Elekta which utilizes a magnetic field of 1.5 Tesla. Both systems acquire MR images prior to treatment and adjust the patient accordingly, similar to CBCT. Figure 1–14 shows the cobalt and linac-MR combined units made by ViewRay. Two other MR guidance systems are under development at the time of this writing: Aurora RT (MagnetTx) in Canada and the Australian MRI-linac at Ingham Institute (Liney et al. 2016). MR guidance in radiation therapy is explained in detail in chapter 16.

1.4.7 Optical Systems

Video-based or optical patient-positioning systems employ surface imaging for pre-treatment patient-positioning adjustments as well as gating. The two commercial systems available use different structured light patterns to achieve this. The AlignRT sys-

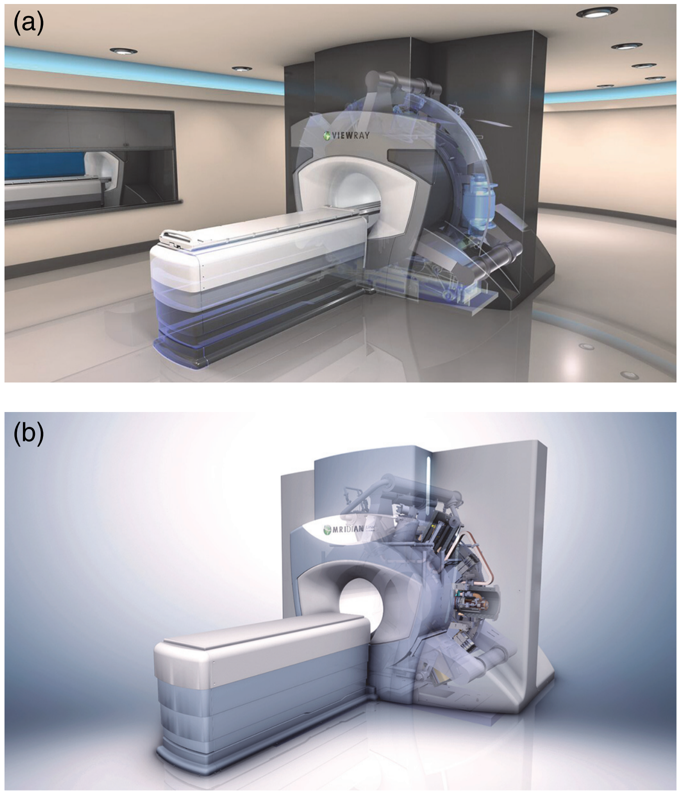

Figure 1–14 (a) The MR-cobalt and (b) MR-linac systems. (Courtesy of ViewRay, Inc.)

tem (VisionRT, London, UK) uses video images in combination with patterns it projects onto the patient to capture and reconstruct 3D maps of the patient's surface (Willoughby et al. 2012). This is done using two or more camera pods installed in the treatment room.

The Catalyst system (C-RAD, Uppsala, Sweden) uses lasers to project structured light onto the surface of the patient, and the reflected light is then captured by video cameras. The projecting and receiving devices are installed in each of three ceiling-mounted pods (Figure 1–15). Both systems compare the captured surface image with a reference one obtained from a treatment planning CT scan or a reference image obtained when the patient is in correct position, determined by other patient positioning means, on the treatment couch. Another relatively new system called Identify (Humediq, Grünwald, Germany) also uses surface imaging.

These patient-positioning technologies are commonly referred to as surface imaging (SI), and patient positioning guidance using this technology is referred to as

Figure 1–15 (a) The VisionRT AlignRt Camera Pod and (b) the C-RAD Catalyst pod. (Images Courtesy of VisionRT and C-RAD.)

surface image guided radiotherapy. Chapters 12 and 13 describe these systems and their clinical applications in detail.

1.5 Summary and Future Developments

Image guidance in radiation therapy has come a long way from visualization using fluorescent screens and radiography using film, and now provides for increased accuracy of patient positioning, which makes dose escalation and margin reduction possible. The need to position the target accurately becomes critically important in the cases of planned dose distributions that are highly conformal to the target. The traditional weekly port films have given way to often daily volumetric imaging using ionizing and non-ionizing radiation, as well as newer methods, such as surface imaging.

Many of the devices listed in this chapter are described elsewhere in this book in more detail.

The future of image-guided radiation therapy will involve a combination of current and developmental imaging modalities into radiation therapy in order to optimize the targeting of tumors. For example, Wertz et al. (2010) proposed fast kV/MV 2D imaging and CBCT for lung imaging. There are also efforts underway to combine positron emission tomography (PET) with linear accelerators. This would lead to biologically guided radiotherapy (BgRT). There is at least one company (Reflexion Medical, Hayward, CA) exploring this option at the moment. Another technique currently being developed is tetrahedron-beam computed tomography (TBCT). The TBCT and BgRT systems are described in chapter 4.

Other technological developments in radiotherapy imaging include the addition of an imaging ring to the radiation therapy delivery system (medPhoton GmbH, Salzburg, Austria). The system consists of a kV x-ray source and a flat panel detector capable of both 2D and 3D imaging, mounted on a ring, that can be integrated into a variety of exiting radiation therapy facilities.

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