Surface Imaging in Radiation Therapy

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After completing this article, the reader should be able to:
- Summarize surface imaging principles and how the technique can improve patient setup, positioning, and monitoring of intrafraction movements.
- Explain various methods of calibration and quality assurance processes for surface imaging.
- Discuss how to implement surface imaging and identify steps that improve the technology’s accuracy and effectiveness.
- Evaluate the benefits and drawbacks of implementing surface imaging.
- Identify strategies for surface imaging use at various treatment sites.

As radiation therapy delivery systems become more complex, the need increases for greater precision in localization and surveillance of the treatment area. Many radiation therapy centers use onboard imaging to localize tumors and closed-circuit television (TV) for surveillance. Onboard imaging can include megavoltage imaging, kilovoltage (kV) imaging, or cone-beam computed tomography (CBCT). Onboard imaging, although accurate, exposes patients to additional radiation and can confirm proper positioning only at a single time point.

Radiation therapists who rely on closed-circuit TV to detect motion typically cannot see patient movements of less than approximately 1 cm. In addition, therapists must pay constant attention to the closed-circuit TV, which is impractical and might not allow the beam to be shut off in a timely manner.

To counter these drawbacks, a more accurate real-time motion detection system is needed. Surface imaging, a tool that combines surface localization and surveillance, is becoming more widely used for setup and intrafraction monitoring. Radiation therapy departments can use surface imaging to improve treatment accuracy and the speed of workflow while reducing radiation exposure to the patient from medical imaging.

The use of surface imaging in radiation therapy gradually has increased since its introduction in other fields in the 1940s. Common applications of surface imaging included imaging of large objects, anthropology studies, and accident scene investigations. However, it has been available for medical use only since the late 20th century. Although surface imaging is not a common tool in clinical oncology settings, other medical specialties, such as plastic surgery,
dentistry, sports medicine, and gastroenterology, routinely use 3-D surface imaging. Surgeons create simulations before starting procedures to aid in surgical mapping and planning. In addition, surgeons can access 3-D surface imaging data in real time, which can shorten decision times for complex surgeries. Plastic surgeons specializing in rhinoplasty commonly use 3-D surface imaging to delineate soft tissue and volumetric changes before and after surgery. In endoscopic procedures with 3-D surface imaging, physicians can access quantitative measurements such as size, depth, and shape of internal anatomy, which can increase the accuracy and precision of an intervention. Furthermore, surface imaging provides the data needed to customize medical devices, such as ear impressions for hearing aids and dental molds.

Surface imaging has evolved greatly since 1944, when a plotting machine was developed to create 3-D images of objects using a technique called stereophotogrammetry. In stereophotogrammetry, measurements from 2 or more photographs are used to estimate the 3-D coordinates on the surface of an object. In 1995, Ras et al improved the technique by using digitized capture to reduce the amount of time needed for manual analysis. Low-cost charge-coupled device (CCD) cameras replaced the old camera systems in 1999, which helped speed up automatic analysis. The first laser scanning system was used clinically in 1991 to monitor the growth of children who had facial deformities. Over the next 5 years, measurements improved, becoming more accurate than those of previous laser scanning systems.

**Surface Imaging**

Surface imaging provides deltas in 6 directions: vertical, longitudinal, lateral, pitch, roll, and yaw. Pitch is a rotation along the horizontal axis, roll is a rotation along the longitudinal axis, and yaw is a rotation along the vertical axis (see Figure 1). Delta is a common term in radiation therapy that indicates a real-time tracking change, in 3 translational and 3 rotational directions, from the initial isocenter point set at the beginning of the treatment fraction. The deltas represent the observed intrafraction deviations from the starting isocenter.

The 2 most common types of surface imaging are optical-based video surface imaging and laser scanning. Modern video surface imaging uses structured or unstructured light patterns and stereophotogrammetry to recreate the surface shape of a 3-D object based on the distortion of the projected light pattern. The system calculates the geometric shifts from the recorded surface to a previously recorded reference surface. Unstructured light is a random light pattern projected onto the surface of a patient or object. Structured light involves illuminating a target with patterns such as dots or grids while the video camera photographs the surface at several frames per second.

Stereophotogrammetry is based on the principle of taking 2 images of the same object from different angles to create a stereoscopic pair. These images contain distance and spatial information about the surface of the object that can be used to create a 3-D shape. For video-based systems, mounting more than 2 cameras to...
the ceiling of the treatment room to record the reflected images increases the 3-D accuracy of the surface image. Using more than 2 cameras also is helpful should the rotating linear accelerator obstruct the cameras’ line of sight during treatment. $^{12,13}$

Digital speckle photogrammetry is an example of surface imaging using structured light. A speckle light pattern is projected onto the curved surface of the target. Stereo cameras receive the reflected pattern, and the system software triangulates the data, creating a 3-D surface model of the object. The 3-D model can be registered with a reference surface image, usually from the treatment planning system (see Figure 2). $^{10}$

Some surface imaging systems use a near-visible light-emitting diode projector and a CCD camera. $^{9}$ The 3 light wavelengths (blue, green, and red) are projected onto the patient. The reflected blue light received by the CCD camera is used to determine the skin surface coordinates. The projected green and red lights show the mismatch of the reference surface vs the actual captured patient surface. $^{9}$

Laser imaging systems sweep a laser beam across the target area, and multiple cameras receive the reflected light from the region of interest (ROI) to help determine the coordinates of the target object. $^{8-10,12,14,15}$ An algorithm then constructs a 3-D model by calculating the difference between the surface of the object and the reference surface. $^{10}$

**Setup and Monitoring**

The body contours from a computed tomography (CT) simulation provide the initial reference surface for the patient. Typically, contours are exported through the Digital Imaging and Communications in Medicine (DICOM) structure set file. DICOM data are imported into the surface imaging software and should be used for the initial treatment. A new, in-room surface imaging capture can be performed at the treatment position once imaging demonstrates accurate patient position. The reference image, either from DICOM data or an in-room capture, provides information for daily patient setup for radiation therapy treatments. $^{10,11,13,15,16}$ An in-room surface imaging capture does not replace the original DICOM data but can be used in place of the DICOM reference each day. The radiation therapist must select the correct type of reference image when performing patient setup and alignment analysis. Choosing the wrong reference could lead to incorrect patient positioning.

Surface imaging also can help monitor patient motion or position changes during treatment. $^{10,14,16-18}$ A separate image is captured and used to determine whether motion occurs after the patient is in the treatment position; this monitoring image serves as the baseline for patient motion. Subsequent delta values are then brought to zero. If motion causes the patient’s alignment to move outside the set tolerance range determined by the surface imaging system, the radiation therapist can hold the beam. If the patient’s position then falls back within the tolerance, the therapist can continue treatment with confidence that the patient is aligned correctly.

When treatment equipment can interface with the surface imaging system, the equipment automatically holds the beam if the patient moves outside the tolerance parameters. A starting point for tolerance is 2 mm.
Surface Imaging in Radiation Therapy

Calibration and Quality Assurance

The acceptance period for surface imaging systems must involve thorough testing and development of routine quality assurance (QA) procedures. Surface imaging requires an initial calibration of the system on installation to ensure that the equipment’s isocenter is aligned with the surface imaging system. A manufacturer representative performs setup and initial calibration. Additional daily QA tests are required to maintain the accuracy of the system. To use the equipment for patient setup and treatment delivery, appropriate calibration and verification guidelines and tools must be available to radiation therapy staff. Each clinical facility can implement more stringent QA protocols and tolerances than are recommended by the manufacturer.

Comparison With Optical Tracking Markers

Marker-based optical tracking in radiation therapy relies on reflective marker photogrammetry to determine the surface of an object. This method differs from surface imaging in that the optical marker is passive and either rests on or is affixed to the patient or to a device that corresponds to the patient’s positional alignment. Surface imaging captures a patient’s entire skin surface to determine the correct position relative to the equipment’s isocenter and to monitor the patient in real time. Optical tracking primarily assists with monitoring respiratory motion rather than with the positioning of a large ROI. Optical tracking can hold the beam should the patient’s breathing pattern fall outside the set tolerance when interfaced with the linear accelerator.

Several methods are used for passive marker attachment. An example of an invasive marker is a bite block with an attached reflective marker array. This method requires creating a custom-fit bite block for the patient and using the block during each treatment session. The markers attached to the mouthpiece help with patient setup and monitoring. Noninvasive optical tracking includes markers affixed to or resting on the patient’s skin; the markers have adhesive backings that adhere to the patient’s skin for gated treatments. The markers must be in the same position each session for the system to provide correct couch shifts. Inconsistent placement can result in patient misalignment.

Figure 3. A model of a daily and monthly calibration plate. Image courtesy of Vision RT.
Surface imaging systems have demonstrated calibration within 1 mm and 1° over several months with little effect from couch rotation.

Implementation

Implementation of surface imaging affects departmental workflow. Any change to workflow in a radiation therapy department can stress staff and negatively affect implementation. As with adoption of any new technology, it is important that all staff members are on board with the technology and well trained in its use. Surface imaging systems involve a steep learning curve. Training is a vital component of the technology's implementation; if the incorrect ROI is used or the system is used incorrectly, misalignment of the patient or unnecessary repositioning can occur. The training should include all personnel involved in the process, including medical physicists, medical dosimetrists, radiation therapists, and, when possible, physicians. Defining the workflow and responsibilities assigned to personnel can ease the transition.

Several factors should be considered when a clinic chooses to introduce surface imaging into the workflow. Using the technology on a small group of patients, such as some patients with breast cancer, is optimal for initial implementation. This practice allows the users to become more comfortable using surface imaging for alignment before increasing the complexity of the variables associated with other treatment sites. As the staff of a clinic becomes more comfortable with surface imaging, the implementation team can add more treatment areas (eg, brain, chest, and pelvis).

To help staff adjust to the new workflow during the initial implementation period, extra time should be added to the appointment. Adjusting the appointment time can ease the stress of maintaining the schedule for therapists and ensure shorter wait times for patients. After staff feels confident in the process and workflow, the appointment time can return to the original timeframe.

Clinical Workflow

The following is a general template of the steps for incorporating surface imaging into the treatment
process, which facilities can modify to meet staffing and equipment needs.

The surface imaging workflow begins with immobilization and patient setup in the treatment position. The radiation therapist activates the surface imaging system and notes the areas of mismatch between the current imaged surface and the referenced surface from the patient’s CT simulation. Next, the therapist adjusts the patient and table to correct for the mismatch. After the patient is aligned based on surface imaging, treatment staff can use standard department protocols to determine whether radiographic imaging is necessary for positioning.

Departments and clinics have used several approaches to determine if radiographs are needed for positioning. One method involves taking a new monitoring capture after the patient is aligned to eliminate (zero) any remaining deltas. The patient is then treated if no daily imaging is needed. For patients requiring further imaging, the therapist confirms the isocenter from the additional images and applies the shifts. A new monitoring capture is taken to detect subsequent shifts, and the therapist delivers the treatment. Zeroing the deltas after imaging and before treatment makes it easier to detect changes in the patient’s position during the entire treatment.

Another method involves aligning the patient and continuing with treatment from that point. If a patient is treated without imaging and the deltas are not taken to zero, the therapist can determine whether the patient falls outside the tolerance from initial setup.28,32 To illustrate this point, if the patient is within tolerance at 3 mm from planned position but then moves 2 mm out of tolerance, the patient is now 5 mm from the planned setup. A monitoring surface capture would show only a 2-mm difference from the ideal position. This approach can be useful if daily imaging is not used and instead surface imaging alone is used to position the patient. Each facility must choose the workflow that best suits its existing processes and workflow (see Figure 4).

Advantages

Surface imaging offers numerous benefits for radiation therapy staff and patients, the primary one being that it is noninvasive and uses no ionizing radiation for image capture. These advantages mean the system does not add to treatment risk or discomfort for the patient.17,23,24 The ALARA (as low as reasonably achievable) principle is an important concept in radiation therapy. Although radiation is administered for therapeutic purposes according to a prescription, the radiation therapist still must limit unnecessary radiation exposure to the patient. Using

![Figure 4](image-url)
Surfacing imaging reduces the radiation dose from imaging because it limits the number of radiographs or in-room scans needed to ensure correct patient position. A surfacing imaging system performs 2 different steps in the treatment process, setup and monitoring, without exposing the patient to additional ionizing radiation. Dose reduction is possible because of the decreased need for repeated imaging. Dose reduction is an especially important concern in the pediatric population. Other benefits include fewer repeated images, the ability to monitor a patient during treatment, a decrease in the amount of immobilization necessary, and reduced need to mark the patient.

In addition to facilitating patient alignment before radiologic imaging, surfacing imaging can limit the number of large shifts or rotations found after radiographic verification. Rotations (ie, pitch, roll, and yaw) are especially difficult to correct without the real-time interactive data provided by surfacing imaging software. Even if CBCT shows rotations, these rotations cannot be corrected easily without a couch capable of 6 degrees of freedom, and the radiation therapist must manually manipulate the patient to make adjustments. Manual adjustment can be a laborious and inaccurate approach. Modifications must be confirmed by additional imaging, and repeating this process means incurring extra time and radiation dose. Even with a couch capable of moving in 6 directions, the range of rotations that can be applied is limited. When used in conjunction with radiologic imaging for patient setup, surfacing imaging facilitates manual adjustments and reduces the number of repeat images, thus limiting unnecessary radiation exposure.

Surface imaging also can be used as a surveillance tool to monitor patient movement and reduce the need for repeat imaging during treatment. It can be difficult for the therapist to observe and quantify small patient movements on closed-circuit TV, even if the patient has reference marks or lines. Surface imaging shows submillimeter movements that can indicate when a patient has moved out of tolerance or has returned to the planned setup. When a patient has returned to the desired position, the radiation therapist can continue treatment without additional imaging. If a patient moves outside the tolerance, the therapist can realign the patient using surface imaging and continue treatment.

Surface imaging systems automatically can interrupt the beam during treatment if the patient moves outside the tolerance set by the system. The ability to hold the beam can be advantageous for all treatment cases, not just gated treatments. The radiation therapist also can set a threshold to define when a surface imaging system should hold the beam by adding a time limit or increasing the tolerance for a particular patient. A time threshold can be helpful for volumetric arc therapy treatments in which a camera can be blocked for a short time during equipment rotation. The possibility of a limited visual field is especially of concern for facilities that have only 1 or 2 cameras. Thus, the therapist might choose a threshold of 1 to 2 seconds to account for potential times the camera is blocked. This particular feature is vendor specific and must be compatible with the treatment equipment.

Respiratory gating and deep inspiration breath-hold techniques can be performed with surface imaging and 4-D CT. Gating is a strategy to decrease the dose to surrounding healthy structures, such as the heart, when treating left-sided breast cancer. Respiratory gating or deep inspiration breath-hold helps decrease irradiated lung volume and thus limits unnecessary radiation dose to critical structures. The advantage of using surfacing imaging to hold the beam during treatment is that no extra devices, such as markers, are attached to the patient. Optical tracking requires passive markers to be placed on the patient, which can be uncomfortable. Surface imaging can monitor whole-body movement for an entire ROI and motion in a smaller area such as breathing motion of the chest.

Surface imaging can enhance patient comfort by decreasing the need for immobilization devices, especially for patients with brain cancer. In particular, patients receiving palliative treatment are more comfortable when there is less or no need for immobilization. Patients are less restricted because the system can detect minute changes in positioning and indicate when the patient is out of tolerance. In addition, because the skin surface, rather than external markers on the patient, is used as a reference, surfacing imaging is not subject to registration errors from a misplaced marker.

Surface imaging allows a radiation therapist to position the patient without the use of skin markings, which
can be advantageous for the patient and the therapist. The patient does not have to worry about preserving marks applied during treatment or experience anxiety about having permanent tattoos. For the therapist, surface imaging can mitigate inherent challenges associated with using lasers for patient setup, such as laser inaccuracies, setup subjectivity, and the unpredictability of patient skin movement. When a clinic moves to eliminate skin markings from the setup process, therapists can be hesitant. However, slowly decreasing the use of skin marks on the patient and relying more on surface imaging can help to alleviate concerns during the transition.

Studies have shown that surface imaging improves workflow. For example, Batin et al. found setup time decreased 45% for breast treatments when changing from a standard workflow using tattoos to a surface imaging workflow. The ability to monitor the patient at all treatment couch angles as well as gantry positions further enhances workflow by decreasing the amount of time needed to verify patient positioning during treatment. With real-time imaging during treatment, the therapist might not need to bring the couch back to zero to verify correct positioning between couch angles, which speeds treatment delivery. Workflow improvements after implementing surface imaging are different for each radiation therapy clinic. The change in amount of time for patient treatment depends on the existing workflow and treatment process.

**Challenges**

Surface imaging has limitations that could impede adoption or use of this technology in radiation therapy clinics. Some limitations, such as workflow or the additional difficulty for patients who have a large body habitus, can be overcome relatively easily. However, equipment cost can be a main barrier to some clinics adopting the technology.

One of the drawbacks of surface imaging is that the system uses the surface contours to align the patient and cannot match surface images to the patient’s internal anatomy. For rigid structures, such as cranial sites, the difference between external and internal anatomy is less important than for other sites. For sites such as the pelvis, the mismatch of surface and internal contours can be a large obstacle to overcome. Tumors that are located posteriorly are less accurately represented by surface imaging on the anterior skin surface, which can lead to a suboptimal setup if treating with smaller margins.

Surface imaging requires a patient’s skin in the area of concern to be uncovered during the entire treatment process. For some anatomical sites such as the breast or chest, leaving the patient uncovered might be the standard procedure. However, for some areas of interest, particularly the pelvis, the patient might have to be uncovered for longer periods than with treatment protocols not using surface imaging. Patients might feel uncomfortable being exposed, which could decrease patient compliance and increase movement during treatment. The radiation therapist can help preserve some of the patient’s modesty by keeping the patient’s genitals or other private areas covered with a washcloth or similar covering that does not interfere with the ROI. Accidental placement of a blanket or clothing item within the ROI is detected as skin surface by the system and leads to inaccurate results. Therefore, it is important that therapists check for any items that might interfere with the ROI.

A multidisciplinary team is required to implement surface imaging. Each radiation oncology center might differ in how it chooses to divide tasks among team members. A medical physicist or medical dosimetrist can export the initial data set while a radiation therapist imports the structure set into the surface imaging system. One clinic might choose to have the medical physicist or medical dosimetrist create the ROI, whereas another site might have the radiation therapist create the ROI. The radiation oncologist typically is involved in deciding whether surface imaging is appropriate for treatment use. The distribution of tasks should be outlined clearly before implementation, and changes should be discussed as they occur. Over time, staff roles can evolve and lead to redistribution of tasks. If implementing surface imaging causes modifications to departmental workflow, the team should discuss the changes with all staff to avoid role confusion or overlap.

Body habitus of patients can affect the accuracy of surface imaging and how it is implemented. Setup can be more difficult with patients who have a larger than
average body habitus. Excess adipose tissue and skin are highly mobile and can decrease the accuracy of the surface imaging system. Adjusting the ROI to exclude extra tissue can help alleviate the problem but will not solve it completely. Radiation therapy staff should take extra care to ensure that the setup for larger patients falls within the expected tolerance.

Setup also can be challenging for patients who have no peaks or valleys in their anatomy, such as those with a flat chest, because there is little topographic variation to help the system detect angular and positional changes. One solution is to set the ROI on the surface imaging system to follow, or wrap around, the patients’ body laterally from the anterior surface for treatment sites within the thorax, abdomen, or pelvis. This gives the surface imaging system more area to use for its algorithm and should lead to a more accurate calculation.

Weight fluctuations can occur in patients during their course of treatment and affect the surface imaging registration. If a patient loses or gains weight, the surface images might not align. Radiation therapists should take a new reference capture after imaging confirms the isocenter to account for weight loss. Monitoring weight changes of patients at risk for weight loss during treatment helps prevent problems related to inaccurate calculations. When a patient has noticeable weight changes, radiation therapists can verify correct setup with imaging as needed. If patient imaging becomes a regular or daily occurrence, the use of surface imaging for that patient might need to be reevaluated.

Patient body characteristics other than habitus also can interfere with surface imaging. Body hair, including facial hair, eyebrows, chest hair, and other types, can affect patient registration and setup because the surface imaging system can misinterpret patches of hair. Removing hair from the ROI can help, but removing all hair is not always practical, particularly for male patients receiving treatment to the chest area. A clinic can choose to ask a patient to remove hair in the ROI if warranted. If the ROI includes the face, a patient’s facial expressions also can affect registration. Appropriately educating patients on how to relax their faces can help alleviate this problem.

Distinctive challenges arise when using surface imaging on pediatric patients. Many of these challenges can be overcome with proper technique. Because children typically have few peaks and valleys on the surface of their chest and abdomen, they have a limited body contour, which makes it difficult for the surface imaging software to delineate the 2 surfaces. Young children also might require anesthesia, which adds to the complexity of identifying an appropriate ROI and keeping the surface clear so the system can perform surface matching. Patients under anesthesia require multiple monitoring devices such as electrocardiogram leads and a blood pressure cuff, and an access point such as a port or central tunneled catheter. These devices can obstruct the surface of the patient, causing the ROI to be incorrect and likely causing the isocenter to be misaligned (see Table).

Regions of Interest

In surface imaging, a software algorithm uses the ROI to calculate the geometric shifts for positioning and monitoring the patient. The ROI must be selected carefully or the setup can be inaccurate, leading to patient misalignment. Every department has its own procedure for conducting surface imaging and a workflow for creating the ROI. Because delineating the ROI is a critical step, the process must be well defined to avoid confusion for staff members. For example, a workflow might begin when a medical physicist or medical dosimetrist exports the DICOM data from the treatment planning system to the surface imaging software. A radiation therapist then inputs the patient data (eg, name, medical record number), imports the DICOM data, and creates the ROIs needed for the patient’s treatment. Finally, the medical physicist or medical dosimetrist checks the ROIs before starting treatment.

Factors that must be considered when creating the ROI differ for each anatomical site. However, for all anatomy, it is important to capture enough of the surface for a valid registration. For instance, if the radiation therapist uses only a narrow region on the anterior surface of the abdomen, the system software might not be able to detect the degree of roll because of the lack of spatial variation. By extending the region laterally to include part of the right and left flank, the system can identify more of the surface curvature, resulting in better measurement of roll error.
The delineation of the ROI can be more complex for certain anatomical areas such as the brain or extremities because the treatment unit, immobilization devices, or medical equipment can obstruct the visual field. For example, an ROI for the brain can be limited because the superior portion of the head is often blocked from the camera’s view and a head fixation device can block the view of the chin. Creating an ROI that includes the forehead and temples can alleviate this problem.\textsuperscript{28,32}

### Anatomical Sites

**Breast**

Breast cancer treatment accounts for a high percentage of patients undergoing radiation therapy. The standard for whole-breast radiation therapy involves portal imaging every 5 fractions with no other setup verifications except setup marks or tattoos. Surface imaging is ideal for breast cancer treatment because the breast is a morphologically detectable superficial target, and surface imaging has been shown to be an effective setup method.\textsuperscript{24,37} After the patient is in the treatment position, surface imaging can help the radiation therapist monitor breast movement during treatment. More complexity is added for surface imaging of patients who have undergone mastectomy. Multiple studies have found that using surface imaging for patient setup results in reproducibility within 3 mm of the target position on portal images.\textsuperscript{17,42}

Published studies have described 2 distinct methods of drawing the ROI for patients undergoing radiation of whole, intact breasts. One method excludes the breast tissue from the ROI but includes the ipsilateral chest wall, base of the breast, and lateral area adjacent to the breast.\textsuperscript{37} Pendulous breast tissue can show movement or tissue deformities between fractions and has led centers to exclude the breast from the ROI. Excluding pendulous breast tissue should not affect the final setup of the patient because the chest wall shows minimal movement and correlates with the breast tissue. The second method includes the breast tissue within the ROI.\textsuperscript{43,44} For both ROI selections, including a small amount of the lateral chest wall on the contralateral side can be beneficial. Both methods have led to similar outcomes for portal imaging approval.

Proper arm and chin placement is important for whole-breast treatment because the chin or arm can alter dose distribution if not in the correct position.\textsuperscript{11,24,42,44} For conventional setups using lasers and skin markings, the patient’s arms and chin usually are checked visually using only the immobilization device. Furthermore, portal imaging does not capture the changes of arm positioning because they fall outside the treatment port.\textsuperscript{11} Surface imaging can capture the treatment area and surrounding body contours, which enables therapists to check whether the chin and arm are aligned with the surface imaging software, minimizing the potential for dosimetric errors associated with arm and chin interference.\textsuperscript{11,25}

Shah et al studied 50 patients with breast cancer for a total of 1258 treatments and found that 86% of portal imaging radiographs had less than 3 mm of deviation when surface imaging was used as a treatment setup method.\textsuperscript{37} The study was conducted on patients undergoing whole-breast radiation therapy. Portal imaging

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### Table

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<th>Challenges</th>
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<td>High cost</td>
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<td>Noninvasive</td>
<td>Surface not always a good match for internal anatomy</td>
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<td>Minimizes radiation dose to patients by reducing need for repeat imaging</td>
<td>Region of interest must be uncovered, potentially compromising patient modesty</td>
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<td>Less immobilization might be needed</td>
<td>Body habitus (ie, obesity, lack of peaks or valleys) can affect setup</td>
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was performed for the first 5 fractions and twice weekly thereafter, correlating to 60% of total patient treatments. Many of the portal images that were rejected had been taken during the first 5 fractions of the patients’ treatment, which could be a result of patient anxiety. Deantonio et al conducted a smaller study with 15 patients but reported similar results. The authors compared surface imaging software with electronic portal imaging device methods and found a negligible difference between the 2 technologies. The findings show random errors of less than 2 mm inside the treatment area. The authors concluded that surface imaging is reliable for daily patient setup.

For breast surface imaging, patients should be set up at the initial verification visit using the DICOM data set from simulation. If the DICOM data and the approved portal images are not in agreement, the radiation therapist can acquire a new reference image. Wiant et al studied 30 patients with intact breasts to evaluate the use of 3-D surface imaging over the entire course of treatment. In this study, all patients were set up using a DICOM surface image from the day of simulation as the reference. The setup tolerance was 3 mm and 3°. The verification portal images and reference image were within tolerance parameters for 20 patients; tolerance was not met for 10 patients. In these cases, surface imaging was used in addition to the portal images for subsequent setup. Researchers believed that the discrepancies between the DICOM reference image and the portal films were caused by differences in patient setup from simulation to the first treatment day or from possible changes in patient contour. If a new reference surface is acquired for subsequent days, the deviation on daily treatments is similar to deviation in DICOM data. Several days of imaging might be needed to verify the accuracy of either the DICOM reference image or the new setup reference.

Partial-breast radiation therapy is becoming more common as a treatment for early-stage breast cancer. A study by Chang et al evaluating 207 treatment fractions sought to compare 3 types of setup techniques for partial-breast irradiation: surface imaging, kV images of the chest wall, and a laser-based setup. The authors concluded that surface imaging was more accurate than chest wall kV orthogonal pairs or traditional laser-based setup.

Surface imaging can be superior to other setup techniques for several reasons. First, breast tissue is mobile and nonrigid and therefore might not always correlate with the chest wall. Kilovoltage images improve accuracy for evaluating bony structures but are not the best choice for imaging soft tissues. This is especially true in larger, more pendulous breasts because the increased distance from the chest wall to the breast tissue can cause additional movement or positioning errors. Traditional laser-based setup with tattoos does not always correlate with the lumpectomy surgical bed. Surface imaging can include the skin at the lumpectomy site as well as surrounding sites.

Brain

Stereotactic radiosurgery (SRS) for brain tumors is a precise treatment that must be monitored carefully to ensure optimal treatment delivery. One method of intrafraction monitoring uses a CBCT scan between delivery of the treatment beams. The additional ionizing imaging ensures proper positioning, including bringing the couch back to zero. In contrast, surface imaging can monitor the patient throughout the entire treatment fraction without additional procedures or extra radiation dose to the patient. Previously, it might have been necessary to bring the couch back to zero between couch angles to ensure patient stability. Unlike other onboard imaging modalities, surface imaging can track and gate the beam in real time for SRS. A study by Gopan and Wu found that the mean deviations for head and neck setups using surface imaging were less than 1 mm in translations and 1° in rotations in all directions.

Surface imaging can decrease the need for strict immobilization in brain SRS because patient movement can be monitored continuously. Standard immobilization using a head frame might not be necessary for every case, and studies have shown comparable clinical outcomes for frameless SRS vs a frame-based technique. Patient compliance is an important factor when choosing a frameless setup. The patient must be able to follow directions and maintain positioning throughout treatment. Therefore, clinicians must balance patient comfort and patient compliance when considering immobilization for cranial SRS.

It also might be possible to limit the need for immobilization in other types of brain and head and neck
Final shifts are determined from the CBCT. After the new reference image is taken, the patient begins treatment. The surface imaging software can detect any movements the patient makes throughout treatment and can hold the beam if that feature is enabled. Mancosu et al suggested a similar workflow for fractionated stereotactic treatments. In this study, surface imaging did not add extra time to the initial verification of positioning. Patient movement is monitored within the ROI, and careful selection of the ROI is important. As previously noted, surface imaging can be used to monitor the patient at different treatment angles.

**Chest**

Radiation therapy chest treatments use either a free-breathing or breath-holding technique. Deep inspiration breath-hold treatments for thoracic tumors can reduce radiation dose to the heart or lung. The patient must be able to replicate the breath hold for every treatment, which can be challenging. Patients undergoing lung treatment might have decreased lung capacity, which impairs their ability to hold the breath consistently. Patients should be able to hold their breath for 20 to 40 seconds with a consistent depth of inspiration.

Several methods help patients complete deep inspiration breath-hold treatments. One method uses a spirometer to measure the amount of air in the lung; however, this can be cumbersome and uncomfortable for the patient. Optical imaging also can be used but requires a respiratory surrogate to be attached to the patient for every treatment. The attached external marker location can vary from day to day, which can lead to inaccuracies and be less comfortable for the patient. Optical imaging also can be used but requires a respiratory surrogate to be attached to the patient for every treatment. The attached external marker location can vary from day to day, which can lead to inaccuracies and be less comfortable for the patient. Optical imaging also can be used but requires a respiratory surrogate to be attached to the patient for every treatment. The attached external marker location can vary from day to day, which can lead to inaccuracies and be less comfortable for the patient.

Thoracic movement from breathing can affect the body contour throughout the breathing cycle. For a free-breathing CT simulation scan, the body contour of the chest is based on the average for the breathing cycle. The average can result in a deviation of the body contour but should not affect patient setup significantly. Capturing a 4-D scan at simulation can minimize...
motion effects but is not necessary unless using a deep inspiration breath-hold technique.\textsuperscript{49} Because the chest anatomy of men and women differs, surface imaging for chest treatments requires distinct implementation strategies. Given the ROI can affect the surface imaging algorithm and a poorly delineated ROI can cause inaccurate setup, using different surface planes provides the best registration data for any ROI created. The female anatomy has more peaks and valleys, which helps the surface imaging system better register the data. Male anatomy typically is flatter, making the ROI selection more critical. The ROI can start at the clavicle and include the chest. Alderliesten et al evaluated the use of surface imaging in stereotactic body radiation therapy for lung cancer.\textsuperscript{49} The authors recommended that ROIs for women include the ipsilateral side of the chest and for men, both sides of the chest.\textsuperscript{49}

Using surface imaging for patient monitoring during chest treatments, specifically for deep inspiration breath-hold treatments, is a quantitative measure that can be used to evaluate chest changes during treatment. Patient drift is possible during deep inspiration breath hold and can alter dosimetric volumes. The changes should be accounted for when a patient begins to exhale. Surface imaging monitors changes in the chest area that correlate to breathing.\textsuperscript{26} A radiation therapist can stop the beam, let the patient exhale, and then resume treatment once the patient resumes the desired level of inspiration according to surface imaging.

**Pelvis**

Compared with other anatomical sites, only limited studies have reported on patient setup with surface imaging for pelvic radiation therapy. Reports of the success of surface imaging for the pelvic region are not as significant as for breast and cranial sites. Still, surface imaging can play a role in radiation therapy of the pelvis.

Krengli et al studied 16 patients who had 3-D conformal prostate treatment.\textsuperscript{50} The study found that portal imaging and surface imaging had a mean difference of 8.5 mm ± 0.13 mm and that these results were similar to results of other setup methods such as tattoos and laser-based methods.\textsuperscript{48} Pallotta et al conducted a study showing similar results with 90% of shifts under 0.57 mm.\textsuperscript{13} A study completed by Bartoncini et al concluded that surface imaging can be adapted for conformal prostate treatment workflow.\textsuperscript{48} Previous studies found congruence in digital portal imaging and surface imaging software.\textsuperscript{35,49,50}

ROI for the pelvic region can include the lower abdomen (below the umbilicus) to the midthighs.\textsuperscript{49} Bladder filling changes the reproducibility of patient setup when using surface imaging. Bladder fullness level most significantly affects the vertical direction. Radiation therapists can reduce this variable by obtaining a reproducible bladder filling set for the patient.\textsuperscript{35,51} Having the patient drink a specific amount of liquid within a set time frame before treatment is reproducible. Another added difficulty of pelvic surface imaging is hair in the pelvic region, which can affect registration of the skin contour. The body habitus of the patient also can affect surface imaging registration. Additional setup problems occur with obese patients and can adversely affect lateral translations.\textsuperscript{35,51} Immobilizing the patient’s legs in a fixed position can help to keep the pelvis in a reproducible position.\textsuperscript{12}

**Pediatrics**

Surface imaging for radiation therapy of pediatric patients can introduce concerns not typically seen in adult patients. Children are especially vulnerable to radiation, and radiation therapists should minimize use of additional radiation when possible.\textsuperscript{13} The nonionizing nature of surface imaging helps reduce the dose delivered during setup and monitoring. Anesthesia can be necessary for younger patients, but adding surface imaging to treatment can reduce the need for anesthesia for some patients. Most children younger than 7 years must be sedated to deliver radiation therapy because they have more difficulty maintaining position throughout the procedure.

Anesthesia introduces risks, can be technically difficult to administer, and can increase the risk of cardiopulmonary morbidity. Use of anesthesia in pediatric patients should be minimized when possible.\textsuperscript{52} Surface imaging can provide a radiation therapist with extra confidence while monitoring a child for small movements and helps the therapist reposition the patient without additional imaging if the tolerance for surface imaging is within the acceptable range. Intrafraction monitoring and repositioning of the patient, if necessary, can help a younger child undergo treatment without anesthesia in certain situations.
For children who require sedation, the surface imaging process can differ for ROI selection. In general, the ROI selection is similar to recommendations for adult ROI selection, with some modifications. Anesthesia requires monitoring of the child while under sedation, which can involve electrocardiographic leads, pulse oximeters, temperature probes, and other devices. In addition, a method with which to administer the anesthesia is required and might involve a port, central line, or peripherally inserted central catheter line, as well as oxygen by nasal cannula or face mask.

Although these devices are medically necessary for a child receiving sedation, the devices can interfere with the ROI. If the ROI includes an area with a positioned device, the area should be excluded from the ROI. In addition, the central line or monitoring devices might overlap the region's isocenter (see Figure 5). In these cases, the radiation therapist should include enough of the patient's contour for a correct match. This can be challenging when adjusting to the process but becomes intuitive over time. Before scanning begins, it is important to safely move as many anesthesia items as possible out of the desired ROI.

The ROI can take up a larger portion of body surface in children than in adults because of a child's small size. The radiation therapist must maintain a large enough ROI for the surface imaging system to detect. The chest and abdomen might be included within the ROI. To resolve problems associated with a child's relatively flat contour, the radiation therapist can wrap the ROI around the patient to his or her lateral edge. In addition, an immobilization device that covers too much of the patient can hinder ROI selection.

Radiation therapy clinics can develop a standard immobilization process for simulating pediatric patients to ensure optimal use of surface imaging. One method could be restricting immobilization to mid-level to ensure that the ROI includes the patient's lateral edge.

Conclusion
Surface imaging in radiation therapy is an emerging technique that can assist in patient setup intrafraction monitoring. The effectiveness of surface imaging for setup and monitoring has been validated by several studies. With proper training and implementation, surface imaging can improve patient care and comfort while reducing dose to the patient because it uses no ionizing radiation and is a noninvasive approach to positioning and monitoring patients during treatments. More data and studies can further describe the challenges and advantages of this promising technique.

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References


Directed Reading

Surface Imaging in Radiation Therapy


To earn continuing education credit:
- Take this Directed Reading quiz online at asrt.org/drquiz.
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Read the preceding Directed Reading and choose the answer that is most correct based on the article.

1. Early 3-D surface imaging evolved from a technique called _______ that uses a plotting machine.
   a. laser scanning
   b. charge-coupled device
   c. stereophotogrammetry
   d. surface imaging

2. In radiation therapy, deltas represent:
   a. 1 of 2 directions used for real-time tracking.
   b. the horizontal axes of surface imaging.
   c. observed intrafraction deviations from the starting isocenter.
   d. the types of cameras used for surface imaging.

3. Structured light involves illuminating a target with _______ or _______ while a video camera photographs the surface.
   a. dots; grids
   b. cubes; grids
   c. dots; cubes
   d. cubes; spheres

4. Stereophotogrammetric techniques are based on taking _______ images of the same object from different angles.
   a. 2
   b. 3
   c. 4
   d. 5

5. The surface imaging reference image can be from:
   1. a Digital Imaging Communications in Medicine (DICOM) structure set.
   2. in-room capture.
   3. portal film capture.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3
6. When introducing surface imaging into a clinical workflow, it can be helpful to:
   1. use a small group of patients.
   2. increase the length of initial appointment times.
   3. define the personnel responsibilities ahead of implementation.

   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

7. Zeroing the deltas after imaging and before treatment makes it easier to detect ________ during the ________.
   a. isocenter changes; setup phase
   b. isocenter changes; entire treatment
   c. changes in patient position; setup phase
   d. changes in patient position; entire treatment

8. Advantages of surface imaging include that it:
   1. is a noninvasive and nonionizing imaging method.
   2. supports patient monitoring.
   3. costs less than alternative imaging methods.

   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

9. Which of the following statements about respiratory gating with surface imaging is false?
   a. No extra devices need to be attached to the patient.
   b. Passive markers must be attached to the patient.
   c. Gating can decrease dose to the heart and lung.
   d. It is used for left-sided breast treatments.

10. Which of the following body habitus issues can cause problems with surface imaging accuracy?
   1. excess adipose tissue
   2. a flat chest area
   3. weight fluctuations

   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

11. Which of the following statements are true about breast treatments and surface imaging?
   1. Breast cancer treatment is ideal for surface imaging because the breast is a superficial target.
   2. Studies have found surface imaging to be within 1 mm of the target position on portal imaging.
   3. Pendulous breast tissue can show more movement or tissue deformities.

   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

12. A region of interest for the face can include all of the following except the:
   a. forehead.
   b. cheeks.
   c. eyelids.
   d. nose.