CT Simulation for Radiotherapy in Breast Cancer Patients

Daniela Martin¹, Dan Dordai¹, Radu Tănăsescu¹, Carmen Popa¹, Daniela Grecea¹, Victor Bogdan¹, Gabriela Tufăscu¹, Aurel Chiș¹, Lavinia Negruț¹, Călin Pleșa¹, Valentin Cernea¹,²

¹“Ion Chiricuță” Institute of Oncology, Cluj-Napoca, Romania, ²“Iuliu Hațieganu” UMPh Cluj-Napoca, Romania

The implementation of 3D conformal and other modern techniques in a radiotherapy department is a complex process that requires sophisticated equipment, but at the same time, a clear and detailed description of the procedures and staff responsibilities involving all planning steps, from CT simulation to the verification of the designed treatment.

Key words: Virtual simulation, Radiotherapy, Breast cancer.

Introduction

The past decades have been extremely important for radiotherapy planning development. The new era of highly selective radiation delivery requires a precise definition of target and organ at risk volumes based on CT, MRI, PET and other advanced anatomical and functional imaging modalities. The aims are: first, to increase tumor control probability (TCP) by tumor dose escalation and second, to reduce the normal tissue complication probability (NTCP) by decreasing the dose to the adjacent healthy tissues, leading to a better quality of life for patients. The implementation of 3D conformal and other modern techniques in a radiotherapy department is a complex process that requires sophisticated equipment, but at the same time, a clear and detailed description of the procedures and staff responsibilities involving all planning steps, from CT simulation to verification of designed treatment.

The purpose of this article is to describe the CT simulation protocol for breast cancer patients in the External Radiotherapy and Brachytherapy Laboratory.

CT Simulator & Virtual Simulation: definition and practical considerations

Virtual simulation (VSIM) was first described by Sherouse et al. in 1990 as the process of radiation treatment planning, using a 3D computer tomography data set which allows full simulation and verification of radiotherapy treatment (1). This process includes the following steps:

1. patient information, positioning, immobilization and reference marking
2. CT scanning for radiotherapy, the patient remains on the table
3. identification of target volumes using anatomical and functional imaging modalities
4. definition of the isocentre relative to reference marks
5. transfer the coordinates to the laser system (LAP)
6. the patient is marked where the laser system illuminates the skin; the patient can be removed from the CT couch
7. delineation of target volumes and risk organs with the addition of isotropic or anisotropic margins
8. definition of the arrangement, size, shape of the fields using MLC’s or individual cutouts, monitor units calculations
9. generation of the dose-volume histogram (DVH)
10. plan revision and modification to best fit the dose constraints
11. generation of digital reconstructed radiographs (DRR)
12. plan approval by physician and transfer to the record and verify system (coordinates: marks for beam centres, field edges, blocks, etc)
13. documentation of the treatment parameters
Basically, the practice of VSIM is based on the communication between a fast CT scanner, equipped with a movable laser positioning system, a workstation (virtual simulation station or treatment planning with export to the laser system enabled) and the planning system (1, 2).

**Preparation for radiotherapy planning:**

**general rules**

**1. Patient information**

Simulation/ CT-Sim and the reason for choosing this approach must be explained in detail to the patient, as well as that the better resolution of soft tissue anatomy for breast tissue, nodal areas, vessels and organ at risk improves target coverage, minimize normal tissue toxicity and takes into account for variability in patient anatomy. An active cooperation of the patient is essential. The patient has to understand the purpose of positioning (which may be unconventional and inconvenient), immobilization, landmarking and CT scanning for radiotherapy. The patient must be educated on the methods he can exert his influence on internal or- gan status (for example to maintain superficial breathing, or breathe holding in deep inspiration in order to reduce the amount of heart within the fields).

**2. Check of the individual anatomy, physiology and abilities**

The anatomical and functional attributes of the patient which may influence the positioning and the compliance to the radiation therapy: age, general health, mental ability, psychological determinants (fear, anxiousness and muscle tension), limitations of movement, body size and weight, the grade and occurrence of pain and other complaints like dyspnœa, discomfort must be recorded.

**3. Positioning and immobilization**

An accurate radiation treatment is based on a convenient and comfortable patient positioning and immobilization, providing maximal set-up reproducibility both for imaging and fractionated radiotherapy (Fig. 1). The patient position and the immobilization device must be identical both on CT-Sim procedure and during the treatment. We use two types of immobilization devices: CIVCO and ORFIT AIO, consisting basically from a breastboard with a number of fixed angle positions 5-20°, elbow and arm supports, a head-rest, a bottom rest and a knee support. Both of these systems can be customized to the patient size and shape to maximize comfort and reproducibility, but also to reduce normal tissue toxicity. If the patent body and the irradiated region are stable and reproducible, internal anatomy deformation remains the principal factor for online correction.

**3.1. Breast supine VSIM**

The patient lies down on the 5-20° inclined breastboard which brings the chest wall parallel to the couch; both arms are extended overhead to lift the breast superiorly and anteriorly away from the heart and to maintain the body symmetry. The patient’s chin should be slightly elevated, or the head should turn toward the non irradiated site if SCF treated (fig.1 b, c); the body should be straight in the midline with relaxed muscles in convenient position. The patient should breathe superficially, with little movements.

The palpable breast tissue and the surgery scar are marked with radio-opaque wire before CT scanning. CT data of the whole breast, tumor bed, nodal regions if involved and critical structures such heart, lungs, brachial plexus, contralateral breast are required for DVH calculations. So, the upper limit – mastoid processus/ horizontal plane above the shoulders and the lower limit 3-5 cm below breast tissue are marked with 2 mm metal ball on the skin. Radio-opaque skin markers are set on anterior midline and right/left mid axillary lines, midway between superior and inferior marked slices (fig. 1a, b). These reference points aligned with the laser lights are defined as the “patient origin” and ensure the set-up consistency.

The patients are scanned with a dedicated CT-Sim GE Lightspeed, 80 cm aperture. The acquisition parameters are: 5 mm section thickness, 120 kV, 200-250mA, for reconstructed images a 44-50 cm field of view and 600/40 WL soft tissue algorithm is use. The complete circumference/contour of the body region must always be on the image. The volumetric CT data are exported to the TPS and a VSIM package is used to define two tangential fields to encompass the breast CTV so that the posterior field edges pass through the medial and lateral metal balls.

The isocentre is defined in the central slice according to the cranio-caudal extension of the outer breast contour and near the chest wall. The position of the CT couch is changed according to the calculated right-left and anterior-posterior translations and the isocentre is marked at the patient’s skin using the laser system. Additionally the patients are marked on the chest wall inferior of the breast to increase the reproducibility of the positioning. All the marks on the patient’s skin will be tattooed.

In the Radiotherapy Laboratory all the CT-Sim processes are performed by the radiation therapists (RTTs) together with the radiation oncologist and the physicist. The VSIM protocol is described below (Table I).
**Protocol for CT Scanning Patients for External Beam Radiation Therapy**

**Patient Positioning**

1. The patient is identified.
2. The patient is asked to remove the wig, jeweler and clothes from the upper body and to barefoot in the dressing cabin. Meanwhile prepare the estimated best set for the concerned region (breast with/without nodal areas) and, if necessary, put the selected mask-precut into the water bath.
3. In order to position patient on CIVCO/ORFIT breastboard with knee rest, firstly ask the patient to sit squarely with the buttocks resting against the bottom stop.
4. The patient is asked to lie straight back while looking forward to minimize any rotation.
5. The head and neck must be resting securely on the headrest; the position of the headrest is adjusted and the bottom-stop is refitted as necessary.
6. Guide patients arms, forearms and hands to appropriate supports and ensure if fit through the CT aperture.
7. Ensure patient flat on the breast board (using sternum as a guide).
8. Adjust CIVCO/ ORFIT AIO breastboard tilt until sternum is parallel to couch top.
9. Palpate patient to ensure sagittal (X) LAP laser runs through suprasternal notch (SSN) and xiphoid process of sternum.
10. Check if the patient will fit through the scanner gantry in this position. If the patient fits through, proceed to the mark up of breast borders. If not, it will be necessary to drop the breastboard elevation until the patient fits through it.

**Mark-up of Breast Borders**

1. Breast tissue, scar and borders are marked with radio-opaque wire.
2. Borders, reference points to be marked:
   - cranial - no more superior than 1cm inferior to SSN.
   - caudal - 2cm inferior to inframammary fold.
     - use contralateral breast for patients with mastectomy.
     - in case of bilateral mastectomy seek clinical guidance.
     - when breast tissue exceeds inferior border:
       - adjust the support
       - use air-equivalent materials
       - prepare a thermoplastic shell
to move breast superior from abdomen
   - medial – midline, at intersection of orthogonal lasers
   - lateral - midaxillary line bilaterally, at intersection of orthogonal lasers

**Patient Scanning**

1. Measure field length by placing LAP lasers on superior margin, zero the bed, move the bed to the inferior border and read the digital display on CT panel. Mark this border on skin.
2. Move couch to half of the length, then using LAP lasers as an indicator draw on lateral rotational and anterior crosses. Mark these points with 2 mm ball.
3. Place 2mm radio-opaque ball on superior and inferior borders. Measure medial and lateral borders on patient skin surface if position is different to metal ball. Record this measurement.
4. Move couch longitudinally until internal CT lasers fall on metal balls, adjusting couch height if necessary.
5. Zero the couch; this is now the zero slice of the scan set on which planning will be done. Move the couch out for the topogram starting position to be placed 5cm sup to superior border/mastoid processes.
6. Inform patient you are leaving the room to proceed with scanning and turn lights up. Ensure door is locked.
7. Proceed to load an anterior topogram. The topogram should extend to 5cm beyond the inferior border to account for divergence in planning.
8. On topogram move FOV to encompass scan range:
   - inferior – 5cm below inferior border
   - superior – 5cm above superior border
   - laterally – 0.5cm outside skin edge
9. Ensure table begin position is divisible by 5 (this ensures CT slice is taken at zero).
10. Click on ‘Load’ and follow instructions to move couch.
11. Press ‘Start’
12. On completion of scan ensure that relevant anatomy is included and is good quality on individual slices. Ensure skin surface is included in field length. See procedure on ‘Recon’ if amendments necessary.
13. Superimpose scan lines on to topogram. Drag (left mouse click and hold down) the anatomy box beside breast scans up to the topogram and release. This will add the scan lines on to the topogram.
14. Click on ‘end exam’ icon.
15. Open patient browser and send scan set to Eclipse.
16. The patient CT data set is imported into Eclipse and a set of tangential beams is defined to best fit the breast anatomy. The isocentre coordinates are transferred to the LAP system and the couch position is changed according to the medio-lateral and anterior-posterior translations.
17. Mark the isocentre on the patient skin.
18. Tattoo anteriors (midline central slice, midline caudal), laterals (right, left) and isocentre as marked on patient skin.
19. Record all details of patient set-up on breastboard set-up sheet and all scan parameters on patient CT-Sim form.
20. Take a photograph of marks as a record and document patient set-up position.
All the patient data, the simulation parameters and the description of the immobilization device are recorded (Table II). The documentation consists of: radiation treatment chart, CT-Sim form, CIVCO breastboard set-up sheet, Orfit AIO breastboard set-up sheet with a short description of the positioning-immobilization device.

The CTVs are outlined on each CT image with full 3D delineation of target volume. The lungs and the heart are contoured for all 3D dose planning and DVHs.

Field parameters are selected according to the breast protocol to be used and the plan is calculated and dose optimized. The plan, including the final isocentre coordinates, which may have changed during plan optimization, is exported to the RTPS together with DRRs. The shift coordinates are printed from the relationship between the plan isocentre and patient origin coordinates. Worksheets and DRRs are printed.

Patients with large or pendulous breasts may require thermoplastic shells to bring the lateral and caudal part of the breast anteriorly, so the amount of lung, heart and abdomen may be reduced; the breast should not be displaced too far superior over the neck (Fig. 2). If necessary, air-equivalent material pieces could be placed in between attaching skin folds. The thermoplastic mask induces loss of skin sparing on irradiated breast, but this is offset by increased reproducibility and reduced degree of axillary and inframammary skin erythema (3).

3.2. Breast prone

In particular cases – large/pendulous breast of soft consistence the breast can be treated in prone position using a"breast prone" immobilization set. The potential advantages are: more homogeneous CTV dose distribution and a reduced dose to the heart and lung. This type of positioning does not allow for lymph node irradiation; also medial and lateral borders, close to the chest wall could be underdosed.

The patient should be laid-down in a convenient position; the contralateral breast is pressed slightly lateral, meanwhile the specific breast hangs into the hole and the ipsilateral arm is stretched over the head.

It is important to prevent the elevation of the ipsilateral shoulder. The body could be slightly rotated; this rotation should be reproducible with large mask fixation and laser lines draw both on the mask and on the patient’s skin. Particular attention should be made to define the reference point.

**Target volume definition**

CT simulation offers the potential to move to a three dimensional planning area, where CTVs and OR can be defined and appropriate margins are added to account for organ motion and set-up uncertainties. The majority of patients with primary breast cancer undergo radiotherapy in adjuvant setting, after complete removal of the tumor, either by conservative surgery, or by mastectomy. There is no GTV in this situation, but CTV only: whole breast and tumor bed after lumpectomy or chest wall for the patients who have undergone mastectomy. When we decide to treat regional lymph nodes, the same principles are applied.

In some cases – palliation for advanced or metastatic disease, the tumor is present in the intact breast, so GTV can be defined and appropriate margins for CTV and PTV are added.

**Whole breast clinical target volume**

Breast CTV considers referenced clinical breast at time of simulation, includes the apparent CT glandular and subcutaneous breast tissue, the tumor bed CTV and excludes pectoral muscles, chest wall muscles, ribs and skin (4, 5). The scar is not included in the CTV, which is defined with 5 mm of skin sparing (Fig. 3).

The consensus definitions of anatomical borders are:

1. cranial: clinical reference, second rib insertion
2. caudal: clinical reference, loss of CT apparent breast
3. anterior: 5 mm under the skin
4. posterior: excludes pectoral muscles, ribcage
5. lateral: clinical reference, mid axillary line, excludes latissimus dorsi muscles
6. medial: sternal-rib junction

---

**Table II: VSIM documentation through treatment planning process**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Radiation treatment chart</td>
</tr>
<tr>
<td>2.</td>
<td>CT-SIM form</td>
</tr>
<tr>
<td>3.</td>
<td>Positioning-immobilization form</td>
</tr>
<tr>
<td></td>
<td>• CIVCO breastboard set-up sheet supine/prone</td>
</tr>
<tr>
<td></td>
<td>• Orfit AIO breastboard set-up sheet</td>
</tr>
<tr>
<td>4.</td>
<td>Photo (immobilization device and patient position must be visible i.e. unambiguously identifiable)</td>
</tr>
</tbody>
</table>
Daniela Martin et al: CT Simulation for Radiotherapy in Breast Cancer Patients

Figure 1: a), b). ORFIT AIO immobilization device: flat cushion, steeper arm holder cushion, baseplate, long and short hand grip, adaptable knee holder; c). CIVCO breastboard: positioning for the right breast and supraclavicular region external beam radiotherapy

Fig. 2. Patients with large, pendulous breasts require thermoplastic shells to increase reproducibility (courtesy to Dr. Katalin Hideghéty, Szeged University)

Figure 3: Breast and tumor bed CTV; tumor bed is marked with titanium clips by the surgeon. The clips contouring is helpful for DRR-EPI comparison
Observations:

a. anatomical borders are highly variable depending on breast size, shape, amount of ptosis and patient position on immobilization device
b. the medial border of the CTV may need to be moved lateral to the anterior midline for large or pendulous breasts
c. whole breast target volume for locally advanced stages or palliation may include pectoral muscle, chest wall muscles, ribs or skin

Tumor bed clinical target volume

The majority of local recurrences have occurred in the same quadrant as the original primary tumor. It is mandatory to define the tumor bed as accurately as possible to achieve local control. The position of the tumor in relation with the scar at the time of operation is not enough. Owing to postoperative complications - edema, hematoma, seroma or vicious scar - it is very difficult to correctly assess the site, size or depth of the tumor bed. The scar is not always immediately on the tumor bed. Moreover we are dealing with oncoplastic surgery which means that the scar is placed periareolar, in order to obtain a cosmetic result (Fig. 4).

Potential sources of contouring discrepancies in this axis include seroma volumes with indistinct borders and low clarity scores, tissue extensions from the tumor bed, and dense breast parenchyma. 85% of microscopic invasive residual disease is localized within 2.0 cm of the primary tumor. So, the part of the breast tissue actually requiring a boost, is that tissue within 1.5 - 2.0 cm of the primary tumor that has not been resected. When the planning CT scan is made and some of the excision cavity is identified, it is not known where that rim of tissue requiring a boost is localized, and, therefore, it is decided to boost the complete 1.5-cm rim of tissue that surrounds the excision cavity, minus the reported minimally free resection margin. According to recent published studies, if information is present on the free resection margins in all six directions, the irradiated boost volume can be reduced significantly (6). It is mandatory that solid and clear definitions must be established for the surgeon, pathologist, and radiation oncologist regarding the orientation of the resection specimen in the breast to prevent misinterpretation of the 3D free resection margins, which would result in geographic misses.

To correctly assess the tumor bed CTV, guidelines recommended 3-5 titanium clips to be placed in the lumpectomy cavity before plastic breast remodeling: one clip on the pectoral muscle at the deep end of the resection site, and additional clips laterally to the resection cavity at mid-height of the former tumor site (fig. 3). The dimensions and orientation of the surgical specimen are recorded by the surgeon in the patient's record. Adequate pathologic examination of the surgical specimen requires specimen orientation and ink.

Breast tumor bed CTV is delineated using the scar tissue and/or seroma and clips visible from the CT scan combined with the clinical, pathologic, and surgical information (7):

1. 3-5 titanium clips placed in the lumpectomy cavity: lateral, medial, anterior, posterior (on the pectoral muscle at the deep end of the resection site), cranial, caudal
2. clips region - volume containing the maximum extent of the clips locations in the medial-lateral, internal-external and cranial-caudal directions
3. tumor bed CTV= lumpectomy cavity clips region + seroma + scar
4. tumor bed CTV= excision cavity + 1.5 cm – free resection margin
5. tumor bed CTV, PTV
   a. excludes chest wall/pectoral muscles
   b. extends to within 5 mm of skin
6. tumor bed PTV= CTV + 0.5 – 1 cm

Chest wall clinical target volume

Chest wall CTV considers referenced clinical chest wall at time of simulation, including the skin flaps, mastectomy scar, the soft tissues down to the deep fascia, but excluding the underlying muscle and ribcage (4, 5).

The consensus definitions of chest wall anatomical borders are:

1. cranial: caudal border of the clavicle head
2. caudal: clinical reference, loss of CT apparent contralateral breast
3. anterior: skin
4. posterior: deep fascia
5. lateral: clinical reference, mid axillary line, excludes latissimus dorsi muscles
6. medial: sternal-rib junction

**Observations:**
- a. in locally advanced breast cancer the skin is included in the target volume
- b. the mastectomy scar may be excluded when extends beyond the typical medial or lateral borders of the chest wall to reduce the dose to the heart and lung below the tolerance limits

**Regional lymph nodes: overview**

Regional lymph nodes CTV may be composed up to three areas: supraclavicular fossa (SCF), axillary (ALN) and internal mammary chain lymph nodes (IMN). Although the indications for lymph node irradiation are not the object of this paper, several aspects must be emphasized:

1. there is no evidence to support axillary irradiation after level 2 dissection, even with extracapsular spread (8)
2. the addition of irradiation to axillary surgery increases the risk of late morbidity (doubles the risk for arm lymph edema (9)
3. sentinel node resection (SNR) without axillary clearance is the new standard for clinically N0 axilla SN negative (NSABP B-32,4)
4. the role of axillary irradiation with positive SN is under investigation
5. irradiation of IMN is controversial, incidence of clinically apparent IMN relapse is low in patients receiving adjuvant systemic therapy
6. prospective, randomized trials show no survival benefit from IMN dissection
7. the role of IMN irradiation is currently investigated by EORTC 22922/10925 and NCI Canada protocol MA20

**Regional lymph nodes clinical target volume**

Imaging of uninvolved nodes for treatment planning is difficult, because they are usually below the spatial resolution of CT, MRI or ultrasound, which use size > 1 cm and excess number of nodes as criteria for involvement.

The consensus definitions of regional lymph nodes anatomical borders are the following (RTOG):

1) supraclavicular lymph nodes
   - a) cranial: inferior border of cricoid cartilage
   - b) caudal: caudal edge of clavicular head/ junction of brachiocephalic axillary veins
   - c) anterior: sternoclavicular node (SCN m.)
   - d) posterior: anterior edge of the scalene m.

2) axillary lymph nodes
   - a) level I
      - i) cranial: plane defined by axillary vessels crossing the lateral edge of pectoral minor m.
      - ii) caudal: base of anterior axillary line, pectoral major m. insertion into ribs
      - iii) anterior: anterior surface of pectoral major and latissimus dorsi m.
      - iv) posterior: anterior surface of subscapular m.
      - v) lateral: medial border of latissimus dorsi m.
      - vi) medial: lateral border of pectoral minor m.
   - b) level II
      - i) cranial: plane defined by axillary vessels crossing the medial edge of pectoral minor m.
      - ii) caudal: the same as the cranial border of level I
      - iii) anterior: anterior surface of pectoral minor m.
      - iv) posterior: ribs and intercostal m.
      - v) lateral: lateral border of pectoral minor m.
      - vi) medial: medial border of pectoral minor m.
   - c) level III
      - i) cranial: pectoral minor m. insertion on cricoid
      - ii) caudal: plane defined by axillary vessels crossing the medial edge of pectoral minor m.
      - iii) anterior: posterior surface of pectoral major m.
      - iv) posterior: ribs and intercostal m.
      - v) lateral: medial border of pectoral minor m.
      - vi) thoracic inlet
3) internal mammary lymph nodes are in the parasternal region, encompassing the internal mammary and thoracic vessels. The CTV includes the upper IMN, first to third intercostal spaces, but may be extended to fifth intercostal space, if there is clinically positive involvement at this level.

**Observations:**
- a. nodal volumes CTV depend on the specific clinical case; the three levels of the axilla can overlap caudal to cranial
- b. variability in depth of the supraclavicular nodes using the location of the SC artery and vein as a
guide has been studied (10). The authors found a linear relationship between the SC nodes depth (ranging from 2.4-9.5 cm) and antero-posterior separation of the patient.

c. traditional definition of the location of the IMN has been questioned (11,12). Using the location of the internal mammary vessels (IMV) some authors found a wide variation in the position of IMN, ranging from 0.8 cm to 6.2 cm, well correlated with the patient anterior-posterior separation. Scrimger et al (12) have found that the lateral position of the IMV in the 95% of cases lay between 2.25- 3.6 cm from the midline

d. CT planning is strongly recommended for patients requiring nodal treatment to adequately encompass CTV and reduce the normal tissue dose

**CTV – PTV margins in external beam radiotherapy**

Geometric uncertainties, like set-up errors, variation in intra- and interfractionally patient position, movement (breathing) and breast swelling must be considered when CTV-PTV margins are defined.

These geometric uncertainties, divided into systematic and random errors can be quantified and controlled by comparing DRR with portal images.

Several studies have shown that a 5 mm CTV-PTV margin in all direction is adequate to account for breast motion during quiet breathing. (13,14). This distance was calculated by measuring the displacement of surgical clips during three types of CT scan: free breathing and breath holding at the end of normal inhalation, respectively normal expiration using a breathing control device.

Combined with random set-up uncertainties and the distribution of the systematic errors, a total CTV-PTV margin of 10 mm seems to provide coverage for 95% isodose CTV surface for most patients analyzed (13,15). There are still questions regarding the margins size in patients with large breast, the variability of the tumor bed position relative to the chest wall requiring probably more generously margins.

In our department the reproducibility of patient positioning was lately improved by using effective immobilization devices: ORFIT AIO and CIVCO breastboards. We use a 0.7-1 cm CTV-PTV margin for breast, tumor bed and nodal areas for external beam radiotherapy techniques.

**Organs at risk**

The organs at risk are heart and major blood vessels, lung, muscles, ribs and contralateral breast. When nodal fields are used, brachial plexus is concerned, so it is important not to overlap with tangential fields by ensuring that the patient position is not changed between the fields. Dose dense chemotherapy is also increasing the risk for brachial plexopathy (16). The dose-volume constraints for organs at risk are listed in table III.

Cardiac toxicity is an important sequela of breast radiotherapy. The relationship between cardiac dose and induced toxicity has not been well defined due to the variation in substructure delineation: whole heart (WH), pericardium, chambers, vessels and valves. With advanced imaging and treatment planning techniques the amount of irradiated heart can be reduced. According to several studies (18,19) cardiac mortality reflect a risk of radiation-induced atheroma in the anterior descending coronary artery (ADC a.) function of total dose rather than the length of the artery exposed.

To prevent inconsistent dose reporting and failure to detect dose-volume correlations, Feng et al. developed a cardiac CT atlas with and without iv. contrast (18). For optimal visualization of cardiac vessels on CT images, a window/level of 150/50 is suggested.

**Contouring tips:**

1. WH starts just inferior to the left pulmonary artery (LP a.), so include in contouring great vessels. Superior vena cava (SVC) can be included in WH contour if contrast is not administrated.

2. The left main coronary artery (LM) starts from the left side of ascending aorta, inferior to the right pulmonary a.

<p>| Table III: Dose-volume constraints* for organs at risk according to QUANTEC (17) |
|-----------------------------|------------------|-----------------|-----------------|---------------------|</p>
<table>
<thead>
<tr>
<th>Organ</th>
<th>Endpoint</th>
<th>DV parameters</th>
<th>Rate (%)</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung</td>
<td>Symptomatic pneumonitis</td>
<td>V20 &lt; 25%</td>
<td>&lt; 20</td>
<td>For combined lung; gradual dose response</td>
</tr>
<tr>
<td>Heart</td>
<td>Long term cardiac mortality</td>
<td>V25 &lt; 10%</td>
<td>&lt; 1</td>
<td>Overly safe risk estimate based on model predictions</td>
</tr>
<tr>
<td>Pericarditis</td>
<td>V30 &lt; 46%</td>
<td>Mean dose &lt; 26 Gy</td>
<td>&lt; 15</td>
<td>Based on single study</td>
</tr>
<tr>
<td>Brachial plexus</td>
<td>Brachial plexopathy</td>
<td>Dmax &lt; 55 Gy</td>
<td>&lt; 3</td>
<td></td>
</tr>
</tbody>
</table>

*The DV constraints we are using currently are V20 < 20%, V30 < 10-15% for the lung and V20 < 10% for the heart.
3. The left anterior descending (LAD a.), inter-ventricular branch originates from the left coronary a. and runs between right and left ventricles.

4. The left circumflex a. starts from the left coronary a. and runs between left atrium and ventricle.

5. The right coronary a. starts from the right side of ascending aorta, on CT appears to start inferior to the LC a.

Dose prescription

**Breast**

- 50 Gy in 25 daily fractions given in 5 weeks
- 40 Gy in 15 daily fractions of 2.67 Gy given in 3 weeks (START B, 6 years follow-up)
- 42.5 Gy in 16 daily fractions of 2.66 Gy given in 3½ weeks (Whelan, Canadian trial, 12 years follow-up)

These hypofractionation regimens have been tested in prospective randomized trials with equivalent results regarding local control or late adverse effects compared to conventional fractionation (19, 20). The consensus is that hypofractionation can be considered safe for breast cancer patients over 50 years with conservative surgery and low risk for recurrence (21, 22).

**Breast boost**

- 10 Gy in 5 daily fractions given in 1 week
- 16 Gy in 8 daily fractions given in 1½ week

When the tumor bed is treated with electron beam, the dose prescription is at Dmax. If we use photon beams to irradiate the CTV boost, the dose is prescribed in ICRU point, at the centre of the target volume.

**Lymph nodes**

- 40 Gy in 16 daily fractions of 2.5 Gy given in 4 weeks; 50 Gy in 25 daily fractions of 2 Gy given in 5 weeks. Doses are prescribed at Dmax (for 6 MV photons beam Dmax is 1.5 cm)

**Palliative radiotherapy**

8 Gy single fraction for bone metastases with uncomplicated skeletal pain; 20 Gy in 4/5 daily fractions given in 1 week are used for cervical spine, meningeal disease and nodal metastases; 30 Gy in 10 fractions given in 2 weeks for brain metastases in patients with good performance status; 36 Gy in 6 fractions given in 6 weeks for inoperable, local advanced tumors in elderly, frail patients with commorbidities

**Breast verification**

Before starting the treatment, portal images must be undertaken for every field, using the locally agreed evidence-based verification protocol (Table IV). This consists of imaging the first three daily fractions, then weekly checks; EPID’s are compared with the CT-generated DRR with 3-5 mm tolerance accepted in matching the anatomical structures. It is recommended that at least three visible structures within the field are outlined and use for comparison: central lung distance (CLD), central flash distance (CFD) and inferior central margin (ICM).

From a comprehensive survey of set-up errors reported in the literature, mean values for both Σ(set-up) and σ(set-up) are around 3 mm and action levels should be set appropriately (14, 23, 24). Breast swelling during radiotherapy may affect the relative accuracy of the measurements used for assessment: breast outline, CFD or ICM. Weekly imaging is recommended for detecting surface outline changes and systematic trends.

Tolerances and action levels vary with the immobilization and treatment technique and also with the compliance of the patient. In vivo dosimetry using a diode or TLD measurement should be performed on first day of treatment in all patients to ensure delivery of the planned dose to each field.

**Table IV:** Protocol for breast verification

<table>
<thead>
<tr>
<th>First day, fraction 1</th>
<th>• Acquire images for all treatment fields, including nodal fields, avoiding dose critical structures, where possible&lt;br&gt;• Set-up error determined by measuring CLD, skin coverage, CFD, ICM, anterior border of lung area/chest wall&lt;br&gt;• Opposed fields cannot resolve set-up errors in 3D&lt;br&gt;• Based on the planner image, correction is made by:&lt;br&gt;  ○ estimating changes to the isocentre and repeat EPI&lt;br&gt;  ○ determining isocentre shift using simulator equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction 2 and 3</td>
<td>• isocentre displacements must be calculable and actionable&lt;br&gt;• evaluation of the systematic component of set-up error will be obtained by repeat imaging over a number of fractions&lt;br&gt;• calculation of corrective couch shifts is difficult with tangential images&lt;br&gt;• any systematic set-up correction applied before fraction 4 ; repeat EPI</td>
</tr>
<tr>
<td>Weekly</td>
<td>• EPI to assess shape change or trends&lt;br&gt;• Correct set-up error greater than the tolerance value, check by repeat imaging</td>
</tr>
</tbody>
</table>
Conclusions

Virtual simulation is a feasible tool for the treatment planning of patient undergoing breast radiotherapy. Compared with conventional simulation, VSIM allows:
1. full 3D viewing and planning of the patient
2. accurate definition and localization of the CTVs and PTV on 3D datasets
3. simulation and verification of the beams
4. integration of multimodality images
5. high precision of patients marking

Successful CT-Sim practice requires changes to the working practice, which must be tailored to the system. This involves flexible working of the radiation oncologists in defining treatment volumes, hard work and skills of the physicists in designing beam geometry and, maybe most important of all, much knowledge and great care by the technologist in positioning, immobilization and every day treatment delivery.

References:

Disclosure: Disclosure and Potential Conflicts of Interest.

Author contributions:
Conception and design: Daniela Martin
Provision of study materials or patients: Daniela Martin, Radu Tănăsescu
Collection and assembly of data: Daniela Martin, Dan Dordai
Data analysis and interpretation: Daniela Martin, Dan Dordai, Victor Bogdan, Gabriela Tufăscu, Aurel Chiș
Manuscript writing: Daniela Martin, Dan Dordai
Final approval of manuscript: Radu Tănăsescu, Valentin Cernea