Radiotherapy is an essential component of the management of early breast cancer. The outcome in most cases is favorable, the majority of the affected patients become long survivors. Breast radiotherapy, however, may increase the risk of non-breast cancer-related morbidities, among which heart diseases rank the first [1,2]. Radiation-induced heart damage clearly depends on the dose exposed to its different structures (3,4). While older radiotherapy planning and delivery significantly improves the control of radiation dose, in many cases a part of the heart, and especially the left anterior descending artery (LAD) located at maximum heart protection during left breast irradiation. Outcome was analyzed in relation to the full CT series acquired in both positions and dosimetric data. Results: Great consistency was found between the tested and original method regarding sensitivity and specificity. The prioritization of LAD dose, and the use of heart dose and position-specific dose constraints as safety measures ensure sensitivity and specificity values of 82.8% and 87.3%, respectively. In an additional “routine clinical practice” series of 60 patients the new method seemed feasible in routine clinical practice. External testing on a 28-case series indicated similar accuracy. Conclusion: We consider this simple clinical tool appropriate for assisting individual positioning aiming at maximum heart protection during left breast irradiation.
Prone positioning was first invented for the irradiation of large-breasted women [23,24]. Indeed, since gravity pulls the breast away from the chest wall, the geometry of a pendulous breast and the tangential irradiation fields gets advantageous in the prone position [12]. Taking the overall population of breast cancer patients, however, prone positioning has such effect in 77–87% of cases only [11,14,15,19]. As a consequence, the position-dependent dose to the LAD or heart also individually differs [11,19,20]. Different approaches exist for selecting the optimal position in left breast cancer cases. Kirby et al. found that a PTV [11,19,20].

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The study was approved by the Institutional Review Board of the University of Szeged, and all the enrolled patients gave their written informed consent to participation. Eligible patients needed postoperative left breast radiotherapy.

Outline of the study

First, a single CT slice image at the middle of the heart (reference plane, $P_{\text{ref}}$) was acquired with the help of an AP scout view in the supine position (Fig. 1A). On that CT scan, the shortest distance between the anterior surface of the LAD and the chest wall ($D_{\text{med}}$) and the area of the heart ($A_{\text{heart}}$) included in the radiation fields were measured after placing a straight line between the border of the ipsilateral latissimus dorsi muscle and the lateral edge of the sternum (Fig. 1B); these data (representing the topography of the heart) were introduced to the calculator together with the patient’s BMI (which correlated with the volumes of the breast and heart) as previously described in detail [19]. The calculator based on a validated statistical model provided the estimated LAD and heart dose differences in the prone vs. supine position of the individual patient. In the first validation set of 100 patients, CT series were acquired in both the supine position and prone position. Conformal radiation treatment plans were generated in both positions using conventional 6 MV tangential photon fields set up isocentrically and median 2 (1–3) individually weighted 6/15 MV segmental fields superimposed on the tangential fields using a multileaf collimator as described [18,19]. Wedges were used in almost all supine radiation plans. A mean dose to the PTV of 50 Gy (25 fractions) and a uniform distribution (−5% + 7%) of the prescribed dose to 95% of the PTV, were aimed at. The consistency of all contouring activities had been ensured by a chief radiation oncologist (ZK) and an experienced radiologist (AC) [26]. Equivalent heart and LAD volume contouring in either setup was ensured by one author (ZK). In the next “routine clinical practice” set of 60 patients, the acquisition of a single series of CT images according to the suggestion of the calculator was aimed at, and a second CT series was taken only if any of the dose constraints approved for the specific position were not reached in the position suggested by the calculator. In this series of patients’ dose constraints were specified on the basis of previously recorded data. The upper range limits of the 90% percentile of dosimetry data in the preferred position were the following: mean LAD dose [MDLAD]: 12.9 Gy and 12.5 Gy, $V_{25\text{Gy,heart}}$: 2.4% and 4.7%, in the prone position and supine position, respectively. In true discordant cases, our strategy for selecting treatment position was to consider the LAD dose as a primary decisive factor.

In the validation set, data on LAD and heart dose differences between the two treatment positions were extracted from the planning system and estimated by the calculator, whereas in the “routine clinical practice” series only the estimated dose differences were available. Analyses were performed on 1. the equivalence of the $P_{\text{ref}}$ with the median plane of the full series of CT scans acquired in the supine position ($P_{\text{med}}$) and 2. the effect of plane miss on the patient-related determinants and choice of preferable position. The sensitivity and specificity of this simple clinical method were evaluated based on the dosimetry data obtained using the topogram for selecting the position ($n = 100$). In the “routine clinical practice” series, the acceptability of the position as predicted by the calculator, the LAD and heart doses achieved without taking 2 CT series, and the need of performing a second CT series and changing position or irradiation technique were analyzed.

External testing

The supine and prone CT series and supine topogram of patients included in the study “individualized positioning for maximum heart and index breast protection during breast irradiation: comparative study between Prone and Supine (Approval: 26/09/2013, B707201318246) were retrospectively used for independent testing. The protocol of patient positioning, delineation and radiation treatment planning has been described [27].

First, $P_{\text{ref}}$ was selected on the topogram. Then, the predictors BMI, $D_{\text{med}}, A_{\text{heart}}$ as measured in $P_{\text{ref}}$ were introduced to the calculator. As a second step, $D_{\text{med}}, A_{\text{heart}}$ were also measured in $P_{\text{med}}$. LAD and heart dose differences between the two treatment positions extracted from the planning system and estimated by the calculator were analyzed. Finally, the correctness of $P_{\text{ref}}$ was evaluated.

Statistical methods

The calculator had been developed based on linear regression models utilizing the patients’ anatomical features, with $\Delta \text{MDLAD}$ and $AV_{25\text{Gy,heart}}$ as dependent variables [19]. With a single cut-off point, a case was classified to prone positioning when the predicted value exceeded that value. Thresholds were optimized based on sensitivity and specificity as calculated from previous

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![Fig. 1. The simple clinical tool generates patient-specific data to predict the benefit of prone positioning. After selecting the reference plane ($P_{\text{ref}}$) at the middle of the heart on the AP scout view (A), a single CT slice is acquired for the measurement of those determinants ($D_{\text{med}}$ and $A_{\text{heart}}$) (B) which operate the calculator to provide estimates of the doses to the LAD or heart.](Image)
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