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In the Context of Treating Breast Cancer, Which Dosimetric Advantages do Volumetric Intensity-Modulated Radiotherapy by Arc Therapy and 3D Conformal Radiotherapy Offer?

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Abstract : Volumetric intensity-modulated arc therapy (VMAT) is gaining popularity in external beam radiotherapy to optimize tumor coverage while sparing healthy tissue. The objective of this study is to compare the dosimetry between the VMAT technique and the conventional 3D tangential technique in the treatment of breast cancer.

- ***Methods and Materials :***

The study is based on a dosimetric analysis of 35 breast cancer patients treated at the Radiotherapy Department of the National Institute of Oncology in Rabat, Morocco, between March 2024 and September 2024. Target volumes (PTV) and organs at risk (heart, lungs, and spinal cord) were delineated on CT images according to ESTRO recommendations. 3D tangential treatment plans and VMAT plans were created for each patient, allowing for a comparative assessment of dosimetric parameters, including PTV coverage (V95), maximum dose (Dmax), as well as mean doses and irradiated volumes of critical organs.

- ***Results:***

The results show significant differences in dose distribution between the two techniques:

- **Target volume coverage (PTV): The 95% coverage of the target volume (V95) is almost identical for both techniques.**
- **Maximum dose in the target volume (PTV Dmax): The maximum dose delivered to the PTV is lower in VMAT (48.98 Gy) than in 3D (50.87 Gy), suggesting that VMAT can reduce hotspots within the target volume. This reduction in Dmax with VMAT could improve local tolerance and reduce side effects in the target volume. 3. 2% PTV: The dose received by 2% of the PTV is also more controlled in VMAT (46.50 Gy) compared to 50.97 Gy in 3D, indicating that VMAT manages to limit the high dose in critical regions of the PTV, which is favorable for dose homogeneity.**
- **Mean dose to the heart and coverage of V17: The mean dose received by the heart is significantly higher in VMAT (3.94 Gy) compared to the 3D technique (2.32 Gy). Similarly, the cardiac volume receiving a dose greater than 17 Gy (V17) is slightly higher with VMAT (2.95%) compared to 3D (2.84%). These results indicate that 3D radiotherapy is more advantageous in terms of cardiac protection, a crucial parameter for patients with cardiovascular risks. 5. Maximum spinal cord dose: The maximum dose achieved in the spinal cord is higher with VMAT (8.58 Gy) than with 3D (4.03 Gy), suggesting that the 3D tangential technique may offer better spinal cord preservation.**
- **Lung dose (V26 and V17): The results show that VMAT reduces pulmonary exposure: the lung volume receiving 26 Gy (V26) is reduced to 13.7% with VMAT, compared to 16.5% with 3D. However, the lung volume receiving 17 Gy (V17) is slightly higher with VMAT (24.6%) compared to 3D (21.2%). This reduction in V26 in VMAT could potentially reduce the risk of long-term pulmonary toxicity, although the increase in V17 requires careful assessment according to each patient's specific risks.**

- ***Conclusion :***

This analysis shows that the VMAT technique offers notable advantages, such as reduced maximum and high doses to the target volume, as well as reduced irradiated lung volume at a high dose. However, the VMAT technique increases the average dose to the heart and the maximum dose to the spinal cord compared to 3D radiotherapy. The choice of technique

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must therefore be guided by dosimetric priorities, particularly the protection of organs at risk, based on each patient's characteristics and risk factors.

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I. INTRODUCTION

Radiotherapy has established itself as an essential component of postoperative breast cancer treatment. It is also the primary method for increasing local tumor control rates while reducing complications in healthy tissue. Radiotherapy primarily targets the chest wall and lymph nodes located above and below the clavicle. Radiotherapy technology is more sophisticated, and to prevent overlap and omission of neighboring rays, minimizing damage to healthy tissue while still reaching the target area should be considered a fundamental criterion for radiotherapy.

Breast cancer radiotherapy treatment can be planned using various methods, including three-dimensional conformal radiotherapy (3DCRT) and more sophisticated planning approaches such as volumetric modulated arc therapy (VMAT). The use of tangent beams in 3DCRT reduces the volume of the ipsilateral lung directly in the beam path. Furthermore, the lung and contralateral breast are not exposed to the beam, as these structures are not in the beam path. The literature abounds with discussions on the use of VMAT, and several authors have demonstrated its dosimetric advantage over non-intensity-modulated methods.

VMAT improves the accuracy of targeted dosing, at the cost of higher low-dose exposure in the lungs and surrounding tissues, which can increase the risk of secondary tumors and other complications.

To reduce these risks, combining 3DCRT with VMAT (hybrid VMAT) has been proposed.

II. MATERIALS AND METHODS

A. Study Population

This study was conducted on a randomized, heterogeneous series of 35 patients treated with radiotherapy at the National Institute of Oncology between January and June 2024.

➢ *Inclusion Criteria*

- Age ≥ 18 years.
- Patient with histologically proven invasive carcinoma of the right or left breast.
- Axillary lymph node involvement.
- Treatment with conservative surgery or total mastectomy.
- Treated with adjuvant or neoadjuvant chemotherapy.
- Indication for adjuvant radiotherapy (performed during RCP) of the breast or the surgical bed with lymph node areas (supra- and infraclavicular).

➢ *Exclusion Criteria*

- Indication for axillary irradiation or MIC.
- Oncoplastic surgery.
- Indication for bilateral irradiation (bilateral breast cancer).
- Metastatic breast cancer at diagnosis.

B. Radiotherapy Planning

➢ *Data Acquisition*

- Patients were positioned supine on an inclined plane with their arms raised above their heads.
- The computed tomographic (CT) images with a 3-mm slice thickness were transferred to Oncentra MasterplanTM software (Elekta) for volume of interest delineation.

➢ *Volume of Interest Delineation*

- Target volumes (PTV) and organs at risk (heart, lung, and spinal cord) were delineated on CT images according to ESTRO recommendations.
- The Clinical Target Volume (CTV) "Breast or chest wall" was delineated using a radiopaque marker (lead wire) applied during the dosimetric scan. The tumor bed ("CTV boost") was defined using surgical clips, visible postoperative changes, preoperative mammogram data, and surgical report data.
- Lymph node volumes ("CTV Sus Clav", "CTV Sous Clav"), the infraclavicular area at levels 2 and 3; the supraclavicular area at level 4.
- The planned target volume or PTV (Planning Target Volume) was obtained by adding a 5 mm margin (followed by a 3 mm skin retraction to avoid optimizing in areas of electronic non-equilibrium) to all the volumes listed above.
- The defined OARs are: the ipsilateral lung, the contralateral lung, the heart, and the spinal cord.

➢ *Prescription De La Dose*

Au niveau du PTV sein et des PTV ganglionnaires, la dose prescrite était de 42 Gy en 15 fractions de 2.8Gy (1 fraction par jour et 5 fractions/semaine). Au niveau du Lit tumoral (PTV boost), la dose prescrite était de 11.2 Gy en 4 fractions de 2,8 Gy en sequentielle.

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➢ *Planification Dosimétrique*

Tangential 3D treatment plans, and VMAT plans, were generated for each patient:

- *3D Conformational Radiotherapy:*

✓ Photons of 6-10 MV to the maximum.
✓ Mono-isocentric technique: a unique isocentre for all the beams, guarantees the reproducibility of the junctions between the "breast or wall" and "hollow and subclavicular" beams by linking the beams to each other. It reduces positioning uncertainties and on the other hand to reduce the duration of the session.
✓ Sein or wall: two opposite tangential beams. The 2 superimposed internal limits. With multi-layers to hide the homolateral lung and the heart.
✓ Sus and under clavicular region: anterior fields, inclined arm of 10-15º on the opposite side.
✓ Multi-likes to hide the organs at risk: the spinal cord
✓ Adapted and personalized ballistics by taking a very limited pulmonary and cardiac volume: - - FIF technique: "Field in Field" or "Field in the field" which eliminates overdose areas. Coin filters: to homogenize the dose.

- *VMAT:*

✓ The multi-drum VMA plans of 6 MV served as a reference for this study. The angles at the start and end of each arc were chosen to optimize the administration of the target dose
✓ The dose being delivered by means of photon of 6 megavolt (MV)

- *Comparative values*

✓ Allowing Comparative Assessment of Dosimetric Parameters, Including PTV Coverage (V95), Maximum dose (Dmax), as well as average doses and critical organ irradiated volumes.
✓ The objective was that 95% of target volumes (PTVS) receive at least 95% of the prescribed dose, PTV max the minimum possible, PTV 2% ≤ 107%
✓ The main objective is to respect good coverage of the target volume and reach the lowest possible dose.
✓ Regarding the oars, different data has been compared:

- For the heart: Dmean, V17;
- For the spinal cord: the Dmax, D2%;
- For the Ipsilateral lung: V17, V26

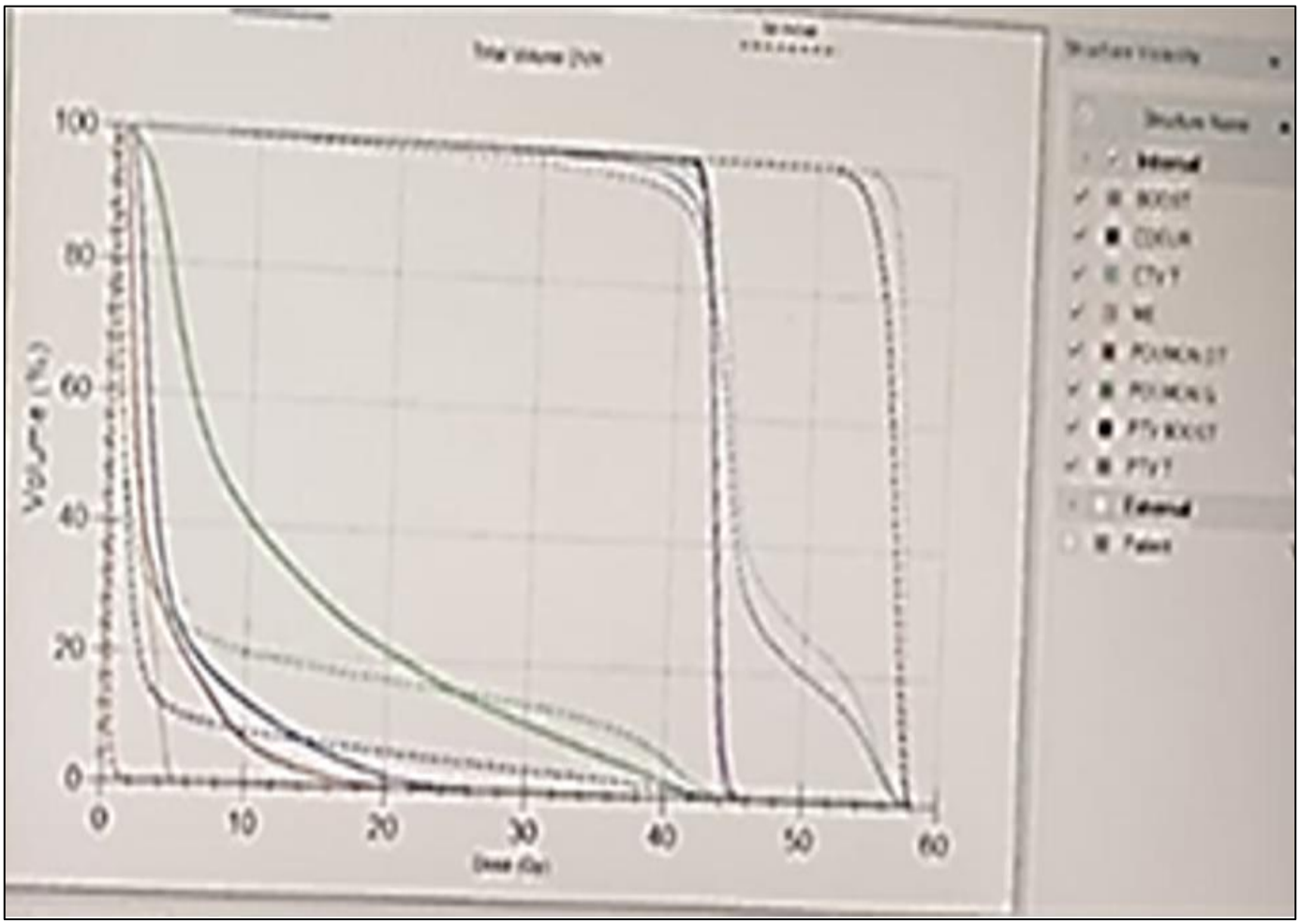

Fig 1 Comparative Diagram of Volumes Received by Target Volumes and OARs by the two Techniques

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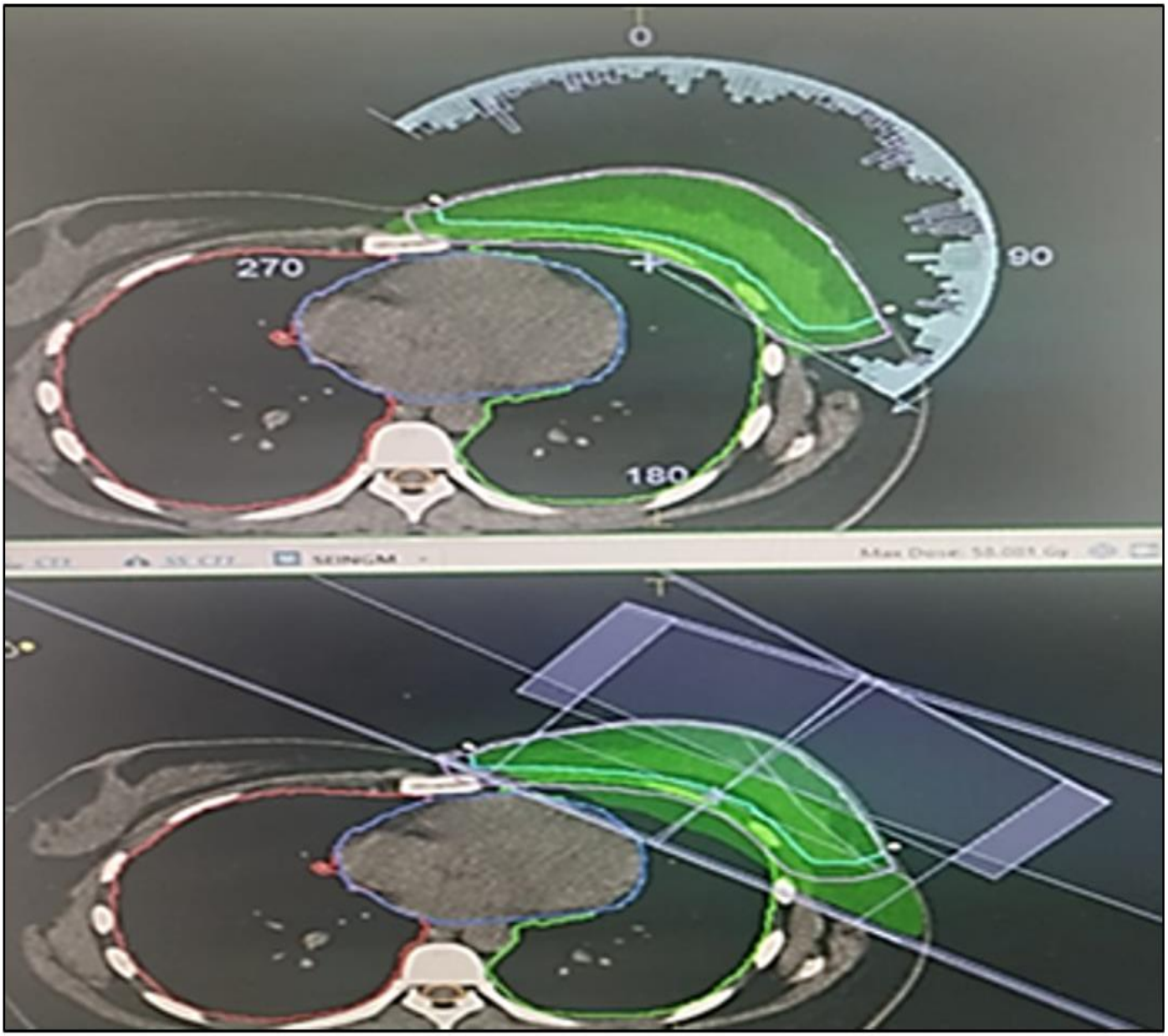

Fig 2 Treatment Planning by arc Therapy VMAT, and Tangential Beams in 3D

- *Dose Distribution*

The analysis of the distribution of the dose focused on the distribution of the isodoses curves and the particular points of the HDV corresponding to the Dosimetric objectives.

III. RESULTS

The study is based on a dosimetric analysis of 35 patients with breast cancer, taken care of in the radiotherapy department of the National Institute of Oncology in Rabat, Morocco, between March 2024 and September 2024

Table 1 Clinical Characteristics of Patients

Patient age: range/n	**(36-68)/35**
Disease laterality	
- Left	17
- Right	18
Surgical status	
- Partial	15
- Total	20
Lymph nodes	
- N+	30
- N0	5

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The Results show Significant Differences in the Distribution of doses Between the two Techniques :

➢ *Target Volume Cover (PTV):*

- The coverage of the 95 % target volume (V95) is almost identical for the two techniques.

➢ *Maximum dose in the Target Volume (PTV Dmax):*

- The maximum dose administered at PTV is lower in Vmat (48.98 Gy) than in 3D (50.87 Gy)
- Suggesting that the VMAT can reduce "hot spots" within the target volume. This DMAX reduction with the VMAT could improve local tolerance and reduce side effects in the target volume.

➢ *PTV 2%:*

- The dose received by 2 % of the PTV is also more controlled in Vmat (46.50 Gy) against 50.97 Gy in 3D.
- This indicates that the VMAT manages to limit the high dose in critical PTV regions, which is favorable for dose homogeneity.

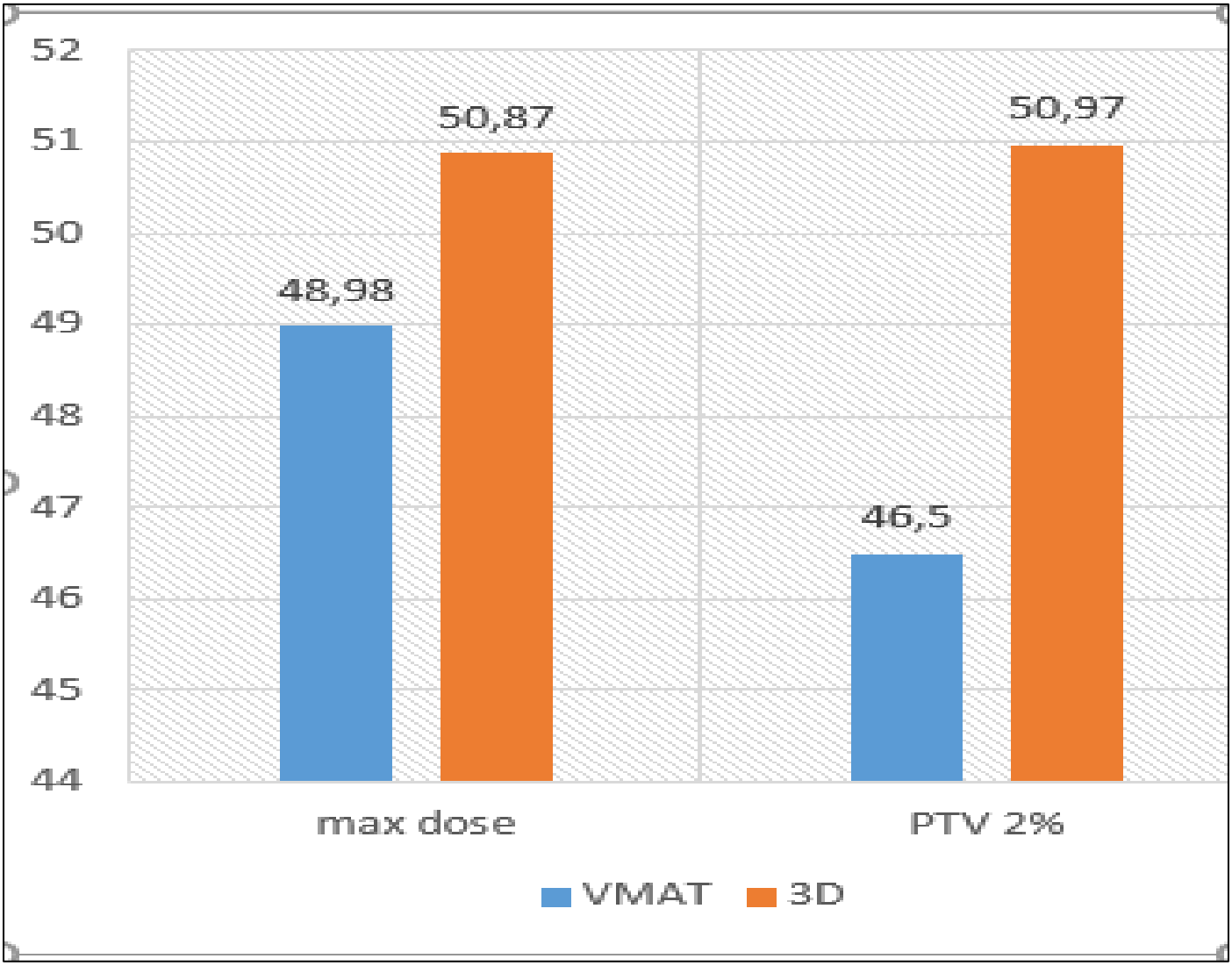

Fig 3 Comparative Diagram of PTVmax and PTV 2% Target Volumes by the TWO Techniques

➢ *Average Dose at the Heart and Coverage of V17:*

- The average dose received by the heart is significantly higher in Vmat (3.94 Gy) compared to the 3D technique (2.32 Gy). Similarly, the heart volume receiving a dose greater than 17 Gy (V17) is slightly higher with the VMAT (2.95 %) compared to 3D (2.84 %).
- These results indicate that 3D radiotherapy is more advantageous in terms of heart protection, a crucial parameter for patients with cardiovascular risks.

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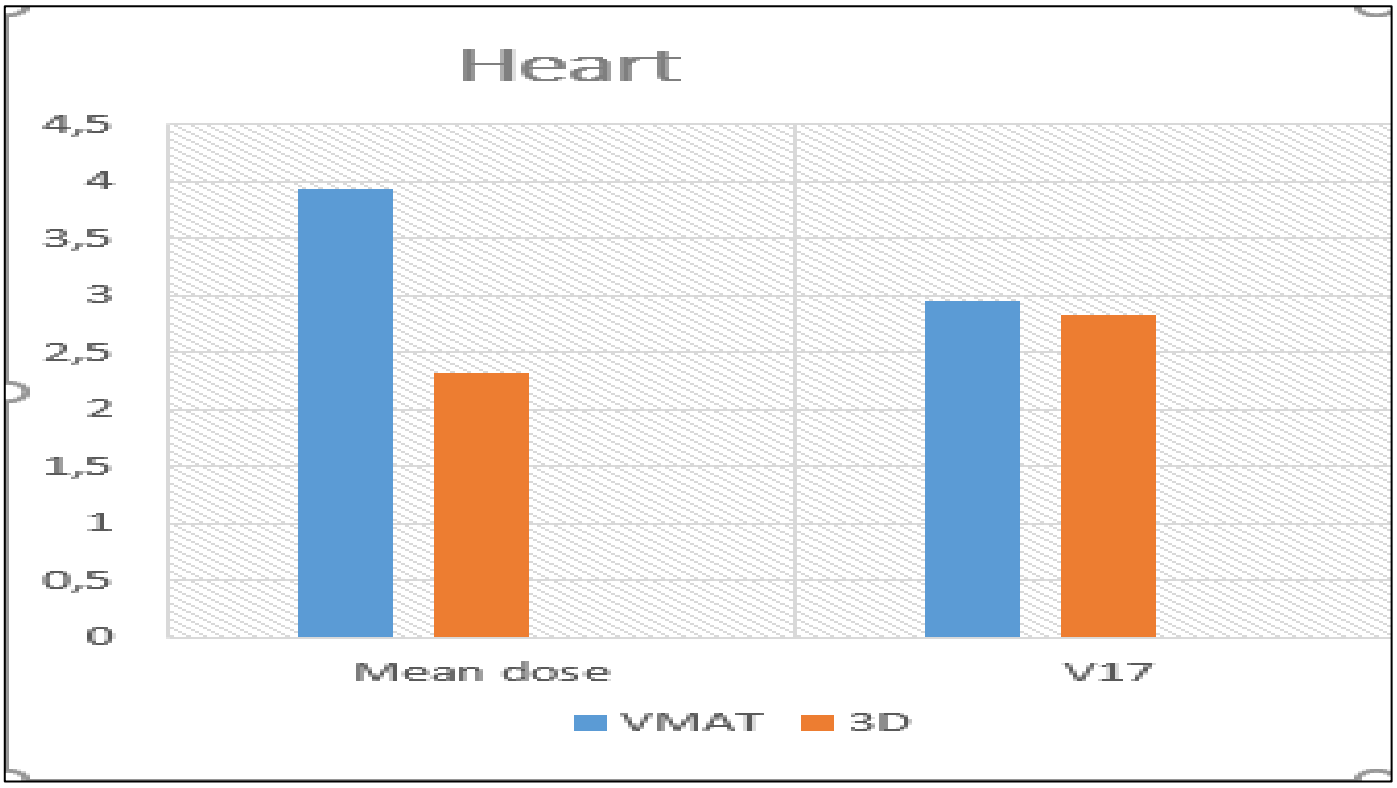

Fig 4 Comparative Diagram of the Volumes Received by the Heart using the two Techniques

➢ *Maximum Dose with Spinal Cord:*

- La dose maximale atteinte dans la moelle épinière est plus élevée avec la VMAT (8,58 Gy) qu'avec la 3D (4,03 Gy),
- This suggests that the 3D tangential technique could offer better preservation of the spinal cord.

➢ *Dose with lungs (V26 and V17) :*

- The results show that the VMA reduce pulmonary exposure: the pulmonary volume receiving 26 Gy (V26) is reduced to 13.7 % with the VMAT, against 16.5 % with 3D. However, the pulmonary volume receiving 17 Gy (V17) is slightly higher in Vmat (24.6 %) compared to 3D (21.2 %).
- This V26 reduction in VMAT could potentially decrease the risk of long -term pulmonary toxicity, although the V17 increase requires careful evaluation depending on the specific risks of each patient.

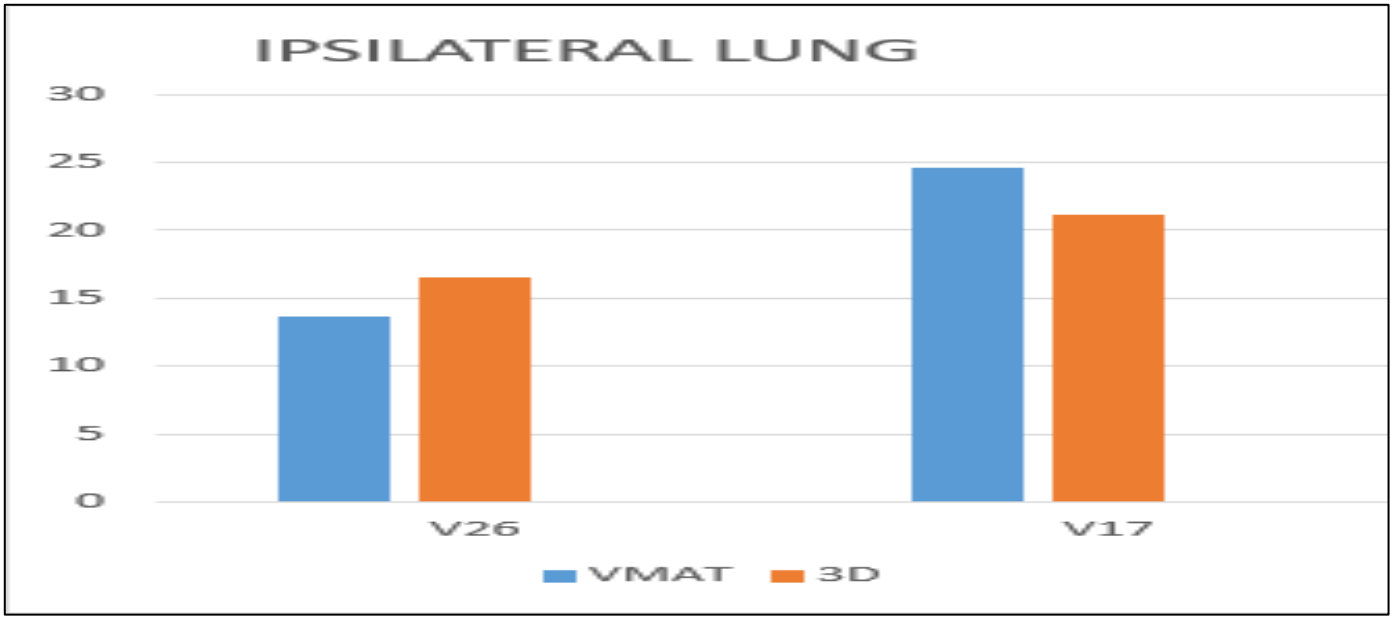

Fig 5 Comparative Diagram of the Volumes Received by the Homolateral Lung by the two Techniques

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IV. DISCUSSION

This study has quantitatively compared VMAT to 3D planning for patients with breast cancer. A higher target dose cover was identical, dose uniformity and dose compliance were observed in the VMAT plans. VMAT plans also had fewer hot spots

The potential of the VMAT to improve the uniformity of the target dose has been well established (1.2,3). The uniformity of the dose has also been linked to better results, as mentioned in the study by Donovan et al. 14 In a phase 2 randomized clinical trial for patients receiving breast and internal breast chain radiotherapy, Ranger et al. (1) have also found that, compared to the large tangible field plans, the VMAT improved lymph node coverage. The Alliance A011202 protocol specifies several dose uniformity criteria in target volumes (3).

Radiotherapy planning is often focused on targeted coverage and healthy tissue dose. The national standards published do not take into account the dose in musculoskeletal regions (4). The clinical experience and published data show that radio-induced fibrosis is correlated with a total dose, the dose fraction and the volume of treated tissue. Minimizing the exposure of the soft tissue of the posterior trunk and the shoulder to radiation can limit the incidence and severity of fibrosis (5).

Regarding the oars, RTC3D would have a tendency to radiate more volume at low dose than VMAT and vice versa less volume in high doses (6).

- *Radio-Induced Pneumopathies*

Graham et al have shown that the probability of developing a grade radio-induced pneumonia ≥ 2 was correlated with total pulmonary volume receiving more than 20 Gy (V20) and as well as in the average dose (7).

Kwa et al, out of a series of 400 patients, also showed that there was a relationship between risk of grade-induced radio-induced pneumonia ≥ 2 and the medium pulmonary dose (8). The risk was 5% for DMEANs between 0 and 8 Gy, 11% 34 for DMEAN between 8 and 16 Gy and 53% for doses> 16 Gy. (These studies took into account the total pulmonary volume by excluding the PTV (9).

According to the study by Goldman et al., No pneumonia was noted when patients received a dose of 20 Gy <30 % in the lung (10).

- *Heart Toxicity*

Darby et al. have shown that the risk of the occurrence of coronary events increased linearly with the average cardiac dose of 7.4% by Gray without a threshold value with a 20 -year decline (11). Nilsson et al. have shown an increase in the risk of coronary stenosis in irradiated patients for left breast cancer compared to irradiations for straight breast cancer for any stenosis grade.

In 3DCRT plans, the dose in the heart is affected by the fraction of the heart present in the path of the tangential field beam. The 5 % dose (D5 %) is therefore strongly linked to maximum heart distance, which is a similar problem in two studies (13.14).

Studies have indicated that the risk of coronary disease is reduced with doses up to 30 Gy, which indicates that the volume receiving 25 Gy should be less than 10 % (12). In the current study, Lev25 Gy for the VMAT plan was on average 2.1 % for the left side which is well below the recommendation.

- *Second Breast Cancer Risk*

In a retrospective analysis of 41,109 patients treated for breast cancer, Boice et al. have found a relative risk (RR) of 1.19 (not significant) to develop a second contralateral cancer after irradiation for breast cancer (15).

Women under the age of 40 having received a dose of more than 1 gy in a contralateral breast are more exposed to secondary cancer than women over 40 (16). It is crucial to take into account the dose within a contribution due to the risk of radio-induced carcinogenesis (17). The contribution of the dose within 3DCRT contralateral is zero or minimal, because there is no direct entry of the beam in the field of treatment (18). However, most VMAT studies agree to show an increase in doses received by the contralateral breast compared to RTC3D (19,20).

- *Skin toxicity*

Three randomized prospective trials comparing RCMI to a conventional technique have been published essentially evaluating skin toxicity (modification of breast appearance, edema, erythema, fibrosis, hyperpigmentation, breast pain, exudative epidermit). These studies have made it possible to show a significant reduction in the acute skin toxicities of grade≥2 and the aesthetic result in favor of the VMAT compared to the RTC3D (6.21,22).

- *Processing time*

The VMAT not only offers profits in terms of dosimetry, but also increased efficiency for planning and execution. A major effect is the decrease in waiting times for patients before and during their management. The VMAT makes it possible to considerably reduce the necessary duration by treatment session, particularly in comparison with the multi -hiking configurations required by 3D plans. It is not due to the ease of installation. Three -dimensional plans constantly require several isocentres, which extends the time to set up since patients must be positioned on various isocentres.

V. CONCLUSION

Whilst it is Challenging to Draw Definitive Conclusions Regarding the Relative Merits of The Two Techniques, the 3D Technique Appears to Offer Enhanced Overall Coverage of Target Volumes, Whilst Demonstracting Greater Sparing of the Heart, Ipsilateral Lung, and contralateral breast. In Contrast, the Technical Vmat Offer notable Advantages,

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Such as Reduced Maximum and High Doses to the Target Volume, as well as a decrease in irradiated lung volume at a high dose. However, the Vmat Technique has been show to enterase the average dose to the heart and the maximum dose to the spinal cord when compared to 3d radiotherapy.

The Use of Vmat in the Management of Chest Wall and Breast Lymph Nodes is on the Rise Within The Domain of Radiation ONCOLOGY. The Selection of Technique Must Therefore Be Guideed by Dosimetric Priorities, Particularly the Protection of Organs at Risk Based on the Characteristics and Risk Factors specific to each patient. Consequently, numerous authors have proposed the use of hybrid plans, integrating three-channel radiotherapy and vmat, with the objective of reducing radiotherapy-related complications.

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