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1 Treatment planning study for irradiation of pulmonary veins under influence of respiratory motion in human data

Contents

Respiration is an intrafractional motion, typically with a large amplitude, which causes the heart and hence the PVs to move. In order to investigate the impact of respiration on cardiac target volumes nine lung cancer patient data sets were used. The 4DCTs were recorded for cancer radiotherapy at MD Anderson Cancer Center in Houston (MDACC, Texas, USA) where patients were treated with proton therapy and IMRT. The same data has been used in previous studies on motion mitigation techniques with scanned carbon ion beams (e.g. [Lue12] [Woe11]). The PV were contoured and the resulting motion pattern, direction as well as motion amplitude of LPV and RPV due to respiration were studied for all cases. Respiration is a known problematic factor also for catheter ablation as it can cause changes in catheter contact force and hence alter the result [Kum12]. For the proposed non-invasive treatment modality with a scanned carbon ion beam proposed here respiratory motion will endanger the treatment outcome as it leads to inhomogeneous dose coverage. Hence motion mitigation techniques are needed. The resulting interplay pattern for all patients as well as gating as a possible motion mitigation technique have been studied and the results will be presented in this chapter.

1.1 Material and methods

For treatment planning studies with the in-house treatment planning software TRiP4D[Ric13], 4DCT data sets, target and OAR contours as well as a deformable image registration for motion assessment in-between the different motion phases are needed. Details on the used input data as well as the used treatment planning parameters will be given.

1.1.1 Treatment planning input data

4DCT

In order to assess the motion of the PV due to respiration, lung cancer patient data was used. The 4DCTs of nine patients were recorded and anonymized at MDACC. The 4DCT data set each consisted of ten motion phases, the reference phase was motion phase five at end exhale. The depth of the respiratory motion was assessed by measuring the difference between the (right) diaphragmatic dome in-between end exhale and end inhale on a frontal view of the 4DCT data. The amplitudes in the superior-inferior (SI) motion direction, the largest motion component in case of respiration, ranged from 2.5mm to 25mm. The varying motion amplitudes are displayed for all patients in table 1.1. Two of the nine patients (patient 6 and 7) displayed a very shallow breathing with an amplitude of less than 5mm. Five patients (patient 1 to 5) had a breathing amplitude between 10mm and 20mm in SI direction. Two patients (patient 8 and 9) were breathing deeply with an amplitude bigger than 20mm. This indicates different breathing patterns as well as varying lung volume expansion and hence heart displacement amongst the studied patients.

Table 1.1: Respiratory motion in the direction of the largest motion component (SI) for all investigated patients. Furthermore the lung tumor location (left lungt (L) or right lung (R)) is stated next to the tumor volume.

patient no	motion [mm]	volume [cm^3]	location (L/R)
1	17.5	236.5	L
2	20	572.2	R
3	10	160.2	R
4	17.5	676.1	L
5	15	372.1	R
6	2.5	706.1	R
7	5	123.8	L
8	25	44.7	L
9	22.5	125.3	L

Segmentation

Segmentation of the LPV and RPV was performed with an in-house display functionality for TRiP (dy) [Hil09]. Its graphical interface allows a contouring on the axial slices of the reference phase of the 4DCT. The contours were checked and validated both by a medical physicist previously working at CyberHeart as well as a cardiologist from Mayo Clinic. As only the motion influence and the motion mitigation possibilities were studied here, contouring of other volumes or organs at risk was omitted. A detailed analysis of the dose to the organs at risk in human data is performed in chapter XXX. The volumes of the contours for the ablation sited for LPV and RPV are presented for each patient in table 1.2.

Table 1.2: Target volume for LPV and RPV for all investigated patients.

patient no	LPV [cm^3]	RPV [cm^3]
1	1.88	5.26
2	3.57	4.79
3	6.49	11.52
4	3.66	3.87
5	2.07	4.37
6	3.40	6.34
7	4.29	6.23
8	6.89	4.84
9	2.92	2.56

Image registration

Non-rigid image registration has been performed with Plastimatch [Sharp07] [Shack10]. The quality of registration was validated with visualization techniques: false color images [Bro07], checker board images [Bro07] as well as a qualitative check of the vector field regularization. These tests were carried out between the two most extreme motion phases: the reference phase at end exhale (motion phase five) and the phase at end inhale (motion phase zero).

1.1.2 Treatment planning parameters

A physical dose of 25 Gy was applied. Three different beam entrance directions were used. For all beam directions the couch was rotated by 90° while the gantry angles were chosen to -45°, 135° and 0°, respectively. With these field number and directions a good sparing of normal tissue, especially of the coronary arteries as well as the aorta and the trachea could be obtained (see chapter XXX). The field directions were validated by a cardiologist from Mayo

Clinic. Treatment plans have been optimized to homogenously cover the CTVs. The grid spacing was chosen to 1mm in x and y direction, respectively. The spacing between the IESs were chosen to 3mm$_{H2O}$. A maximal contour extension of 1.1 times the focal spot size was chosen as well as a distal contour fall off of 4mm$_{H2O}$. TRiP's 'all points divergent beam' algorithm was used to calculate the absorbed dose.

Motion trajectories

As the reconstruction of the 4DCTs was based on the time scale a phase-based motion state detection was employed. A Lujan motion type was chosen for the motion trajectories [Luj99]. In order to consider possible divergence in the respiratory motion pattern of patients, different periods (6 s and 8 s) as well as different starting phases (0° and 90°) were used.

Margins

The original CTV was expanded by different margins investigated in the treatment planning study. Isotropic safety margins of 3mm, 5mm and 7mm have been chosen. The ITV volumes used as the final target were generated from the original CTV contour as well as the CTVs with margin, so that potential range variations were considered in the margins.

1.1.3 Analysis

For comparison of the resulting dose coverage dose-volume-histograms (DVHs) were studied. The V95 (measure of dose coverage) and V107 (measure of over dosage) of the CTVs were analyzed. As an indicator for the dose homogeneity, the width of the dose fall off was determined by analyzing the difference D5-D95. The stated values have been evaluated for all beam applications (static, interplay, gating). Static thereby means that no motion was included, resulting in a 3D case. This is only used as a reference value for the 4D cases interplay and gating, as the static case represents the ideal, but not deliverable dose distribution. Furthermore motion-volume-histograms (MVHs) were generated in order to assess the resulting motion of the PV due to respiration.

In order to study correlations between the diaphragm motion and the motion of the PVs as well as the motion and the resulting dose analysis values, linear Pearson correlation analysis were carried out. The explained variance r is reported for significant correlations ($p < 0.05$).

1.2 Results

In the following the results of the motion assessment as well as the treatment planning studies will be presented. The motion is shown as the relative displacement to the reference motion phase. For the treatment planning study different dose analysis parameters (dose steepness, dose coverage and over dosage) will be shown and compared for different cases (static, interplay and gating). For two exemplary patient cases the treatment planning was expended to rescanning within the gating window. The expected treatment time will be discussed.

1.2.1 Motion assessment

Using the resulting deformation maps from deformable image registration the motion of the ablation sites of LPV and RPV was assessed. Motion volume histograms (MVHs) displaying the relative displacement of every voxel of the investigated volume to the reference phase in all three motion directions were generated. The mean and standard deviation of these displacement values in each motion phase of LPV and RPV are plotted for all patients and motion directions in figure 1.1 and 1.2, respectively.

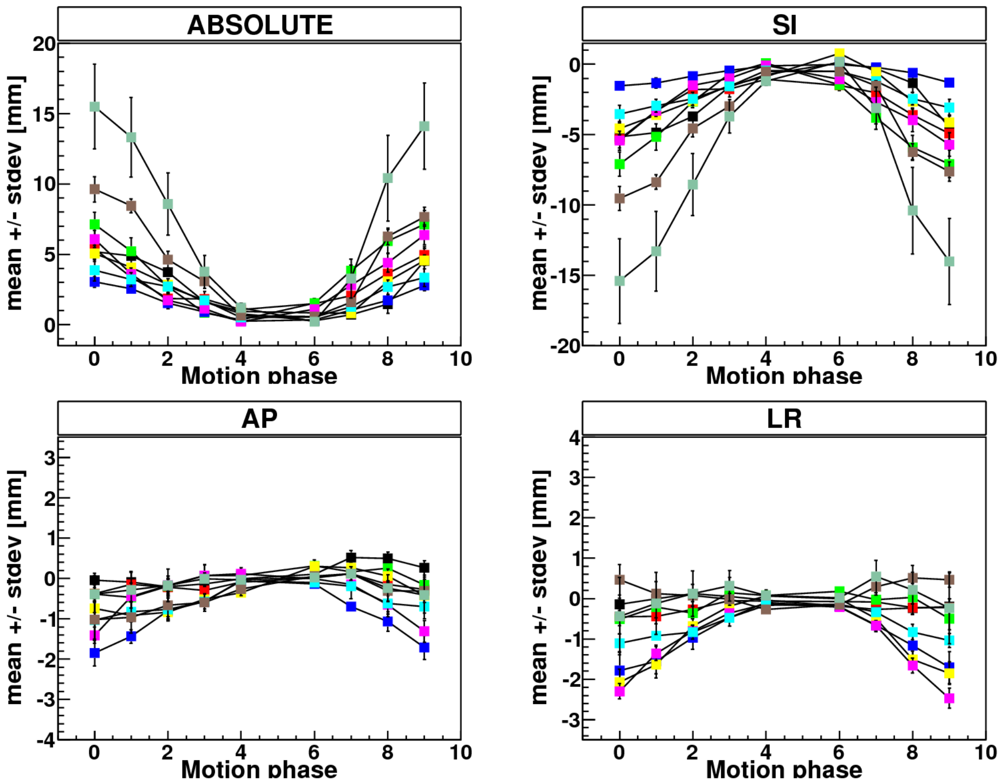


Figure 1.1: Motion amplitude of LPV due to respiration for all patients in all motion directions. (patient 1: black, patient 2: red, patient 3: green, patient 4: blue, patient 5: yellow, patient 6: pink, patient 7: turquois, patient 8: brown, patient 9: olive)

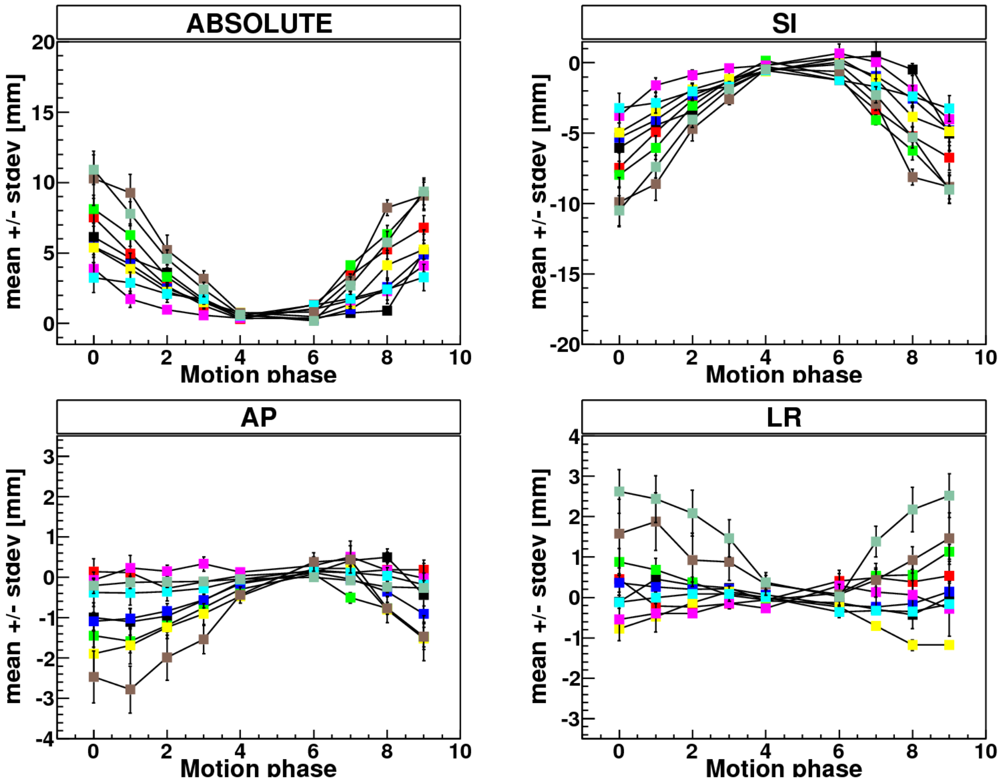


Figure 1.2: Motion amplitude of RPV due to respiration for all patients in all motion directions. (patient 1: black, patient 2: red, patient 3: green, patient 4: blue, patient 5: yellow, patient 6: pink, patient 7: turquois, patient 8: brown, patient 9: olive)

The relative displacement around end exhale (reference phase; motion phase five) is small for all motion directions and patients. The displacement relative to the reference phase is highest around motion phases zero at end inhale.

The mean and standard deviation of the displacement between end exhale and end inhale for the different motion directions are shown as numerical values in table 1.3 and 1.4 for LPV and RPV, respectively. Depending on the patient the absolute displacement of the pulmonary veins were found to vary between three millimeters and more than one centimeter. The largest motion direction is SI, resulting in the largest contribution to the absolute displacement. The average in SI direction over the entire volume reaches up to 15.5mm (average of (6.76 ± 3.8)mm) for LPV and 10.9mm (average of (6.76 ± 2.5)mm) for RPV. The other two motion directions show a much smaller displacement. In AP direction the maximal motion is less than 2.5mm (standard deviation of less than 1mm) and in LR the PVs move less than 2.7mm (standard deviation of 1mm).

Over all patients, the mean absolute displacement in-between end exhale and end inhale of the LPV is (6.8 ± 3.6)mm and (6.8 ± 2.5)mm for RPV. For the SI direction, the mean displacement over all patients is (-6.4 ± 3.8)mm and (-6.6 ± 2.4)mm for RPV.

Table 1.3: LPV: Mean and standard deviation of target motion in-between end exhale (motion phase five) and inhale (motion phase zero) for all investigated patients.

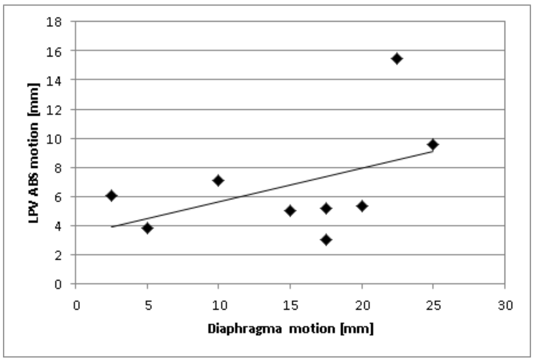
patient no	ABS [mm]	SI [mm]	AP [mm]	LR [mm]
1	5.17 ± 0.48	-5.16 ± 0.48	-0.05 ± 0.18	-0.14 ± 0.15
2	5.37 ± 0.62	-5.33 ± 0.62	-0.38 ± 0.22	-0.45 ± 0.22
3	7.14 ± 0.85	-7.09 ± 0.85	-0.39 ± 0.40	-0.51 ± 0.37
4	3.03 ± 0.39	-1.53 ± 0.26	-1.85 ± 0.32	-1.78 ± 0.47
5	5.06 ± 0.57	-4.55 ± 0.48	-0.75 ± 0.19	-2.07 ± 0.32
6	6.08 ± 0.61	-5.43 ± 0.68	-1.41 ± 0.20	-2.30 ± 0.19
7	3.87 ± 0.75	-3.55 ± 0.63	-1.03 ± 0.47	-1.11 ± 0.23
8	9.61 ± 0.90	-9.53 ± 0.86	-1.02 ± 0.52	0.47 ± 0.38
9	15.50 ± 3.02	-15.40 ± 3.01	-0.39 ± 0.46	-0.44 ± 0.96

Table 1.4: RPV: Mean and standard deviation of target motion in-between end exhale (motion phase five) and inhale (motion phase zero) for all investigated patients.

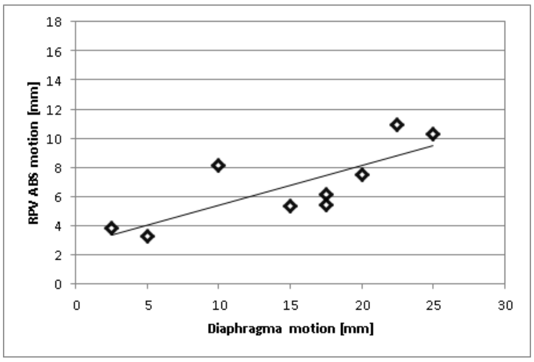
patient no	ABS [mm]	SI [mm]	AP [mm]	LR [mm]
1	6.12 ± 1.43	-6.03 ± 1.41	-1.00 ± 0.37	-0.11 ± 0.16
2	7.51 ± 1.35	-7.47 ± 1.35	0.14 ± 0.32	0.46 ± 0.41
3	8.12 ± 0.98	-7.94 ± 0.95	-1.45 ± 0.28	0.88 ± 0.33
4	5.46 ± 0.57	-5.33 ± 0.59	-1.09 ± 0.22	0.36 ± 0.23
5	5.37 ± 1.51	-4.96 ± 1.44	-1.89 ± 0.56	-0.77 ± 0.12
6	3.85 ± 0.46	-3.77 ± 0.48	-0.07 ± 0.20	-0.55 ± 0.52
7	3.25 ± 1.08	-3.21 ± 1.06	-0.38 ± 0.34	-0.12 ± 0.10
8	10.30 ± 1.91	-9.89 ± 1.74	-2.47 ± 0.64	1.58 ± 0.85
9	10.90 ± 1.06	-10.50 ± 1.06	-0.21 ± 0.19	2.62 ± 0.54

Possible correlations between the underlying respiration amplitude (see table 1.1) and the displacement of the ablation sites for the PVs have been studied (see figure 1.3). It can be stated that in AP and LR direction, no correlation was observed. In case of SI displacement the results varied depending on the target volume. While no correlation was observed between the SI displacement and the diaphragm motion in the ablation site of the LPV, the site for RPV showed a strong linear relationship ($r=0.79$, $p<0.05$). This resulted in a strong correlation between absolute diaphragm motion and RPV ablation site ($r=0.79$, $p<0.05$). For the LPV again no correlation was observed in the absolute displacement.

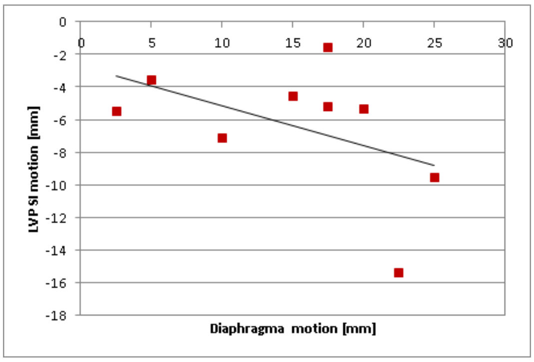
It should be noted that these findings are based on lung cancer patients (see table 1.1), which can alter the breathing pattern and heart motion and hence the result. It is unclear whether atrial fibrillation patients would display the same motion dependence and correlation results, though the result was independent of the tumor position in the left or right lung wing.



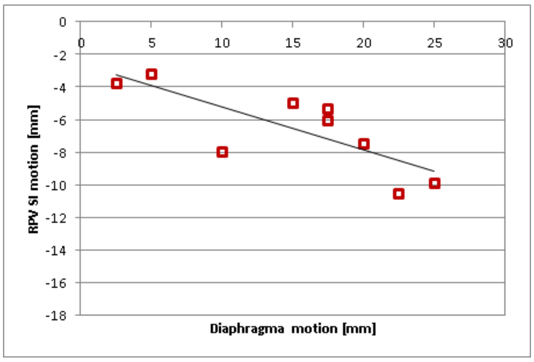
(a) LPV: absolute



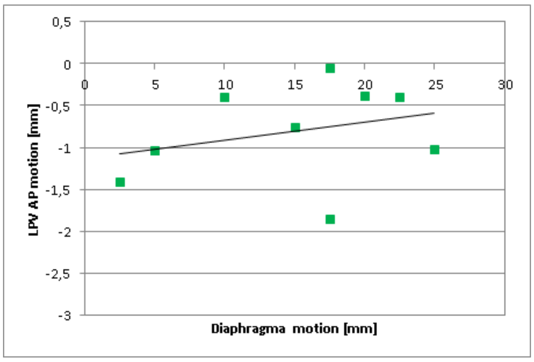
(b) RPV: absolute



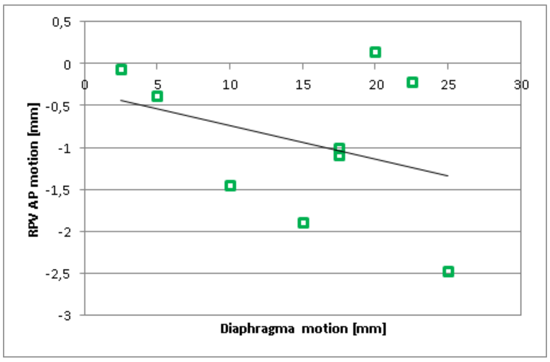
(c) LPV: SI



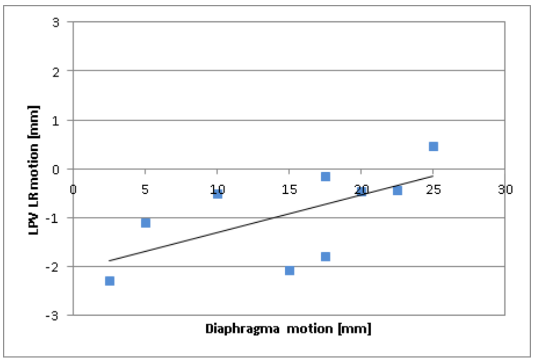
(d) RPV: SI



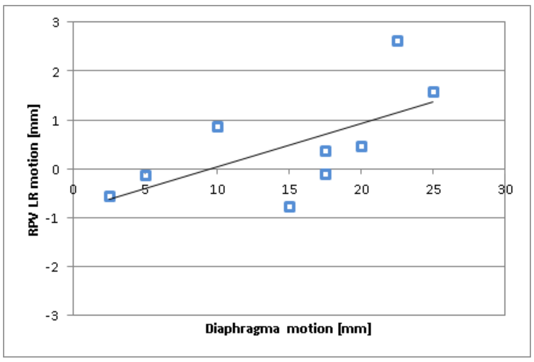
(e) LPV: AP



(f) RPV: AP



(g) LPV: LR



(h) RPV: LR

Figure 1.3: Motion of the ablation site of LPV (left column) and RPV (right column) in relation to the diaphragmatic motion of the respective patient. The motion is plotted as mean value of: absolute displacement, SI displacement, AP displacement and LR displacement, respectively.

The overall displacement field between the two extreme states, end exhale and end inhale, for two exemplary patients with a small motion amplitude (patient 7) and a large motion amplitude (patient 9) are shown in figure 1.4 and 1.5. In order to visualize the location of the displacement, an axial cut of the reference state CT is underlayed. The absolute values of the displacement vectors are shown as contour plots.

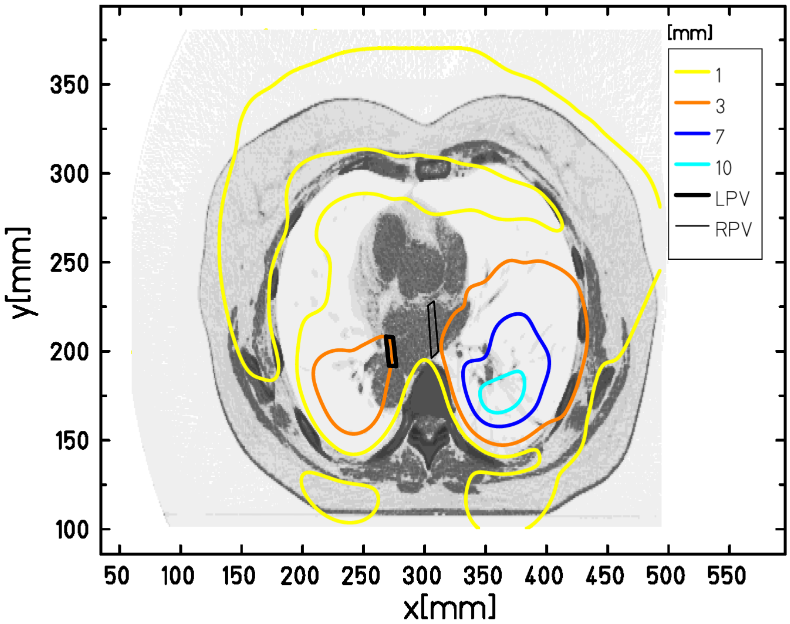


Figure 1.4: Contour plot of Patient 7

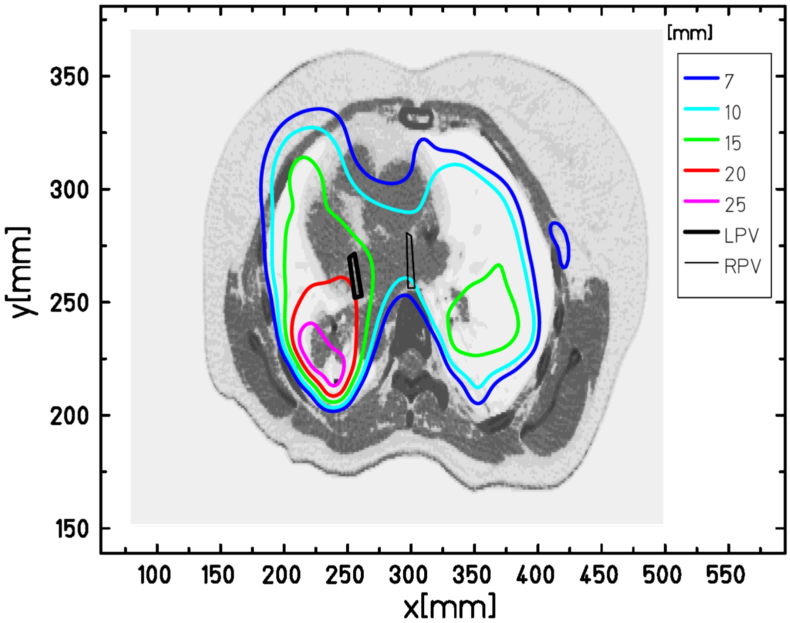


Figure 1.5: Contour plot of Patient 9

1.2.2 Motion mitigation techniques for respiration

The absolute motion amplitudes of up to 1cm due to respiration are expected to yield dose inhomogeneity when not compensated for. The resulting Interplay effect and dose deposition was studied for every patient for different motion patterns and different margins to the target volumes. The dose analysis values V95, V107 and D5-D95 were assessed and plotted. For comparison also the corresponding values for the 3D case (static) are shown. As shown in section 1.2.1 the motion displacement in the motion phases around end exhale (motion phase four to motion phase six) are rather small in all patient cases. Hence gating has the potential to be a well-suited motion mitigation technique to overcome the influence of target volume motion due to respiration. The results of the stated dose values in case of gating on the stated phases will also be presented.

Dose deposition

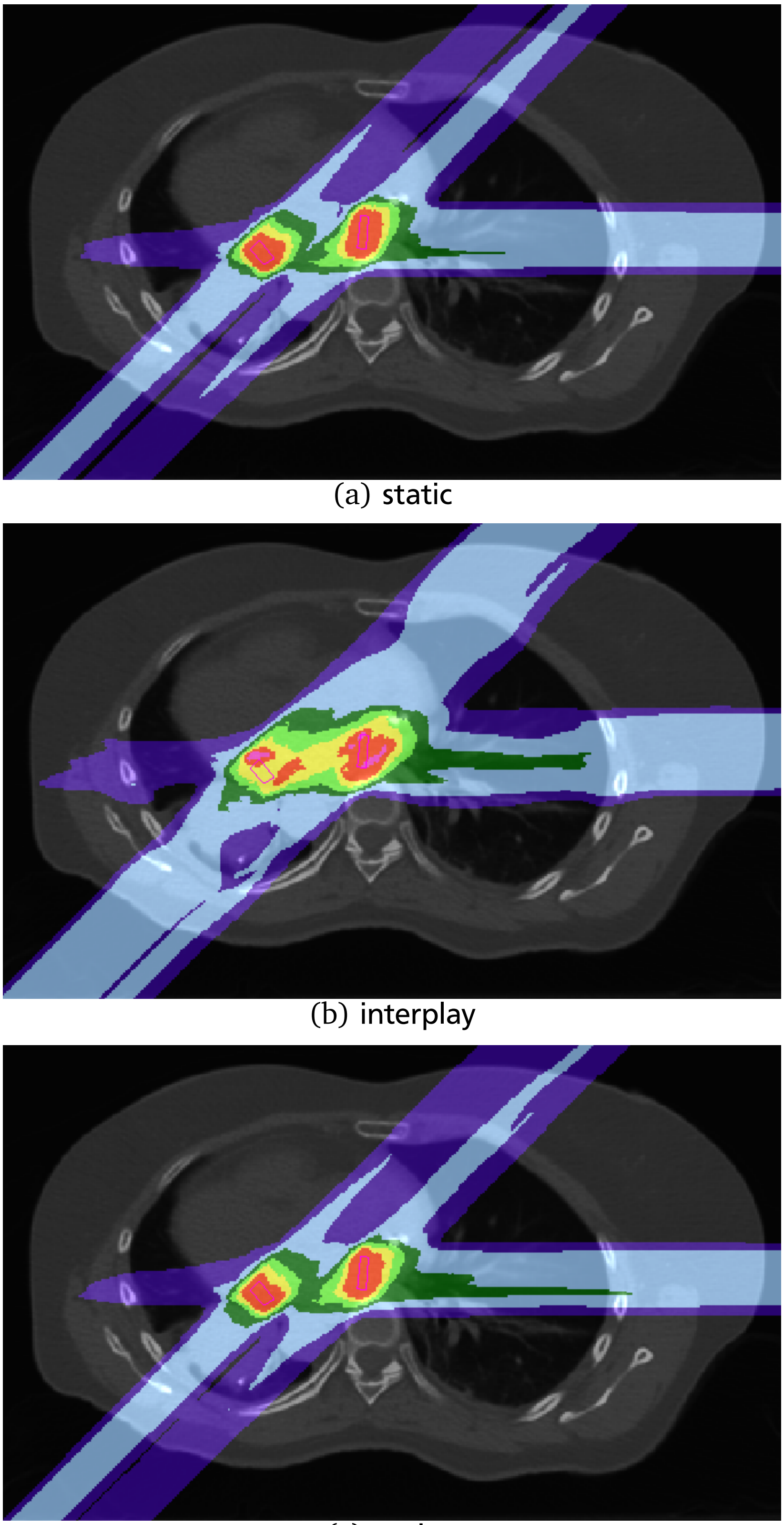
A representative dose deposition for all studied techniques (static, interplay and gating) is shown exemplary for patient 9 (as this is the patient with the largest PV motion amplitude) in figure 1.6. Gating and interplay are shown for a motion with a period of 6 s and a starting phase of 0°. The target volumes LPV and RPV were irradiated simultaneously and a margin of 3mm was added. It can already been seen from this dose cut figures that gating around end expiration drastically improves the outcome compared to interplay and yields a result which is comparable to the static case.

In order to assess the dose information for the whole volume the DVHs of all patients were analyzed and compared for dose steepness, dose coverage as well as over dosage. The average results over all patients with the resulting standard deviation can be seen in figure 1.7. A more detailed analysis can be found in appendix XXX, where the values are plotted for each patient (figures 1.11 - 1.19) and all corresponding numerical values are shown.

For interplay it can be seen that the results are dependent on the used motion period and starting phase, the safety margin and the studied patient case. The underlying deformation map with its motion amplitude does not enable a prediction of the magnitude of the interplay effect. The correlation between absolute motion amplitude of the left and right PV and the resulting V95 value for 3 mm Margin were assessed for all studied motion patterns (lujan motion with period of 6s or 8s and starting phase of 0° and 90°) and patients. A correlation between the dose coverage and amplitude resulted in some cases where a motion period of 6s was chosen (LPV: $r=0.69$ and starting phase of 0°, $r=0.86$ for starting phase of 90°; RPV: $r=0.73$ for starting phase of 90°; all $p<0.05$). Nevertheless these results could not be verified in the other motion cases and hence no clear dependence between target volume displacement and dose coverage was found. Concerning safety margins a tendency towards improved dose homogeneity and coverage can be seen with increasing margin. However, a study of the linear correlation between the two values for all the different motion patterns and all patients showed no clear dependence.

Gating yielded improved results compared to interplay in all studied cases. This is valid for dose steepness, dose coverage as well as over dosage. Especially dose coverage and over dosage are comparable to the static results for all patient and motion patterns (e.g. patient 1, V95 of 100% for all studied motion patterns and safety margins in RPV). In some patients the dose coverage is better with added safety margins (e.g. patient 9, V95 with no margin for motion period of 6 s and starting phase of 0° is 94.14 % for LPV, a V95 of 99.92 % can be achieved for the same motion pattern with a margin of 3mm). Also in dose steepness a bigger safety margin tends to improve results (e.g. in LPV of patient 6 with motion period of 8 s with starting phase of 90°: D5-D95 = 4.63% with margin of 3mm versus D5-D95 = 4.21 % with margin of 5mm). Nevertheless a linear correlation between safety margin and dose coverage value as well as dose homogeneity has not been found in all patients and all motion pattern. Dose steepness is the only value which can not be drastically improved by gating compared to interplay in all cases. Patient 2 for example has a D5-D95 value of 6.79% for gating with a safety margin of 3mm (motion with period of 6 s and starting phase of 90°), which is only slightly under the interplay result of D5-D95=8.41% for the same safety margin and motion. Nevertheless the dose steepness value of interplay in this particular patient case is already lower than in other cases (e.g. patient 1, LPV: D5-D95=10.60% for a safety margin of 3mm and a motion with a period of 6 s and a starting phase of 90°; patient 9, LPV: D5-D95=20.93% for a safety margin of 3mm and a motion with a period of 6 s and a starting phase of 90°).

A method to further improve the dose steepness can be rescanning in the gating window. This has been studied for two patient cases and the results are shown in the next section (Rescanning of gated volume).

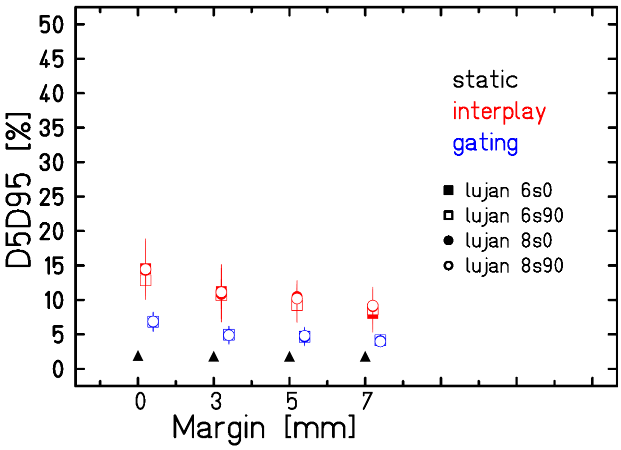


(a) static

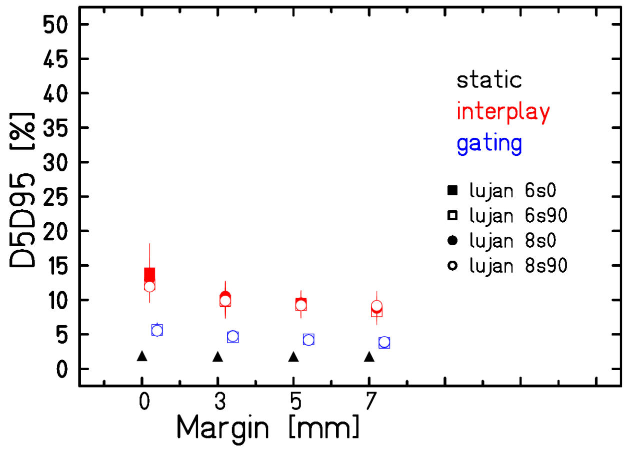
(b) interplay

(c) gating

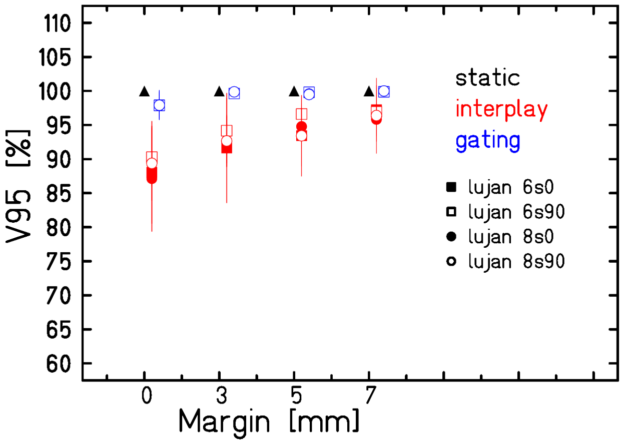
Figure 1.6: Dose distribution of patient 9 for static (a) as well as interplay (b) and gating (c) at motion period of 6 s and a motion starting phase of 0°. The target volume has an added margin of 3mm. The improved outcome of gating compared to interplay can already be seen in these dose cuts.



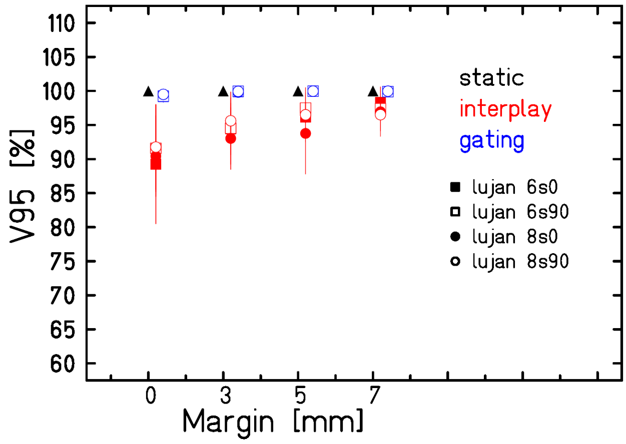
(a) D5-D95: LPV



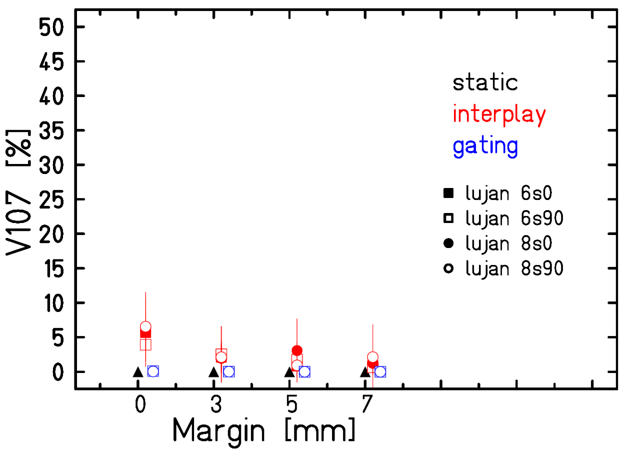
(b) D5-D95: RPV



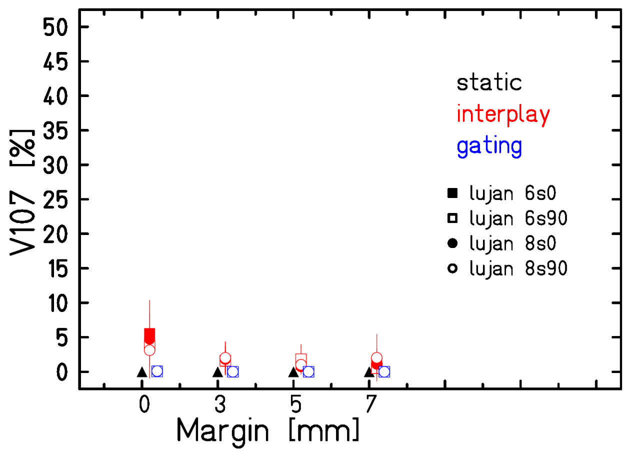
(c) V95: LPV



(d) V95: RPV



(e) V107: LPV



(f) V107: RPV

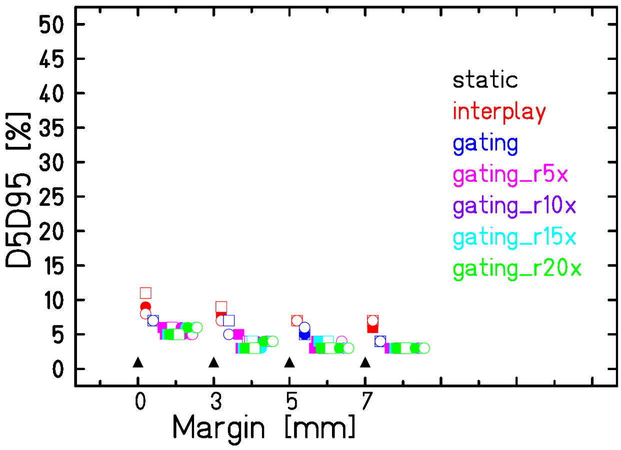
Figure 1.7: Mean value and standard deviation of dose analysis parameters D5-D95 (dose homogeneity, first row), V95 (dose coverage, middle row) and V107 (over dosage, last row) over all patients. The LPV (left column) and RPV (right column) were studied seperately. Static (black) as well as interplay (red) and gating (blue) are compared for four different motions and different safety margins.

Rescanning of gated volume

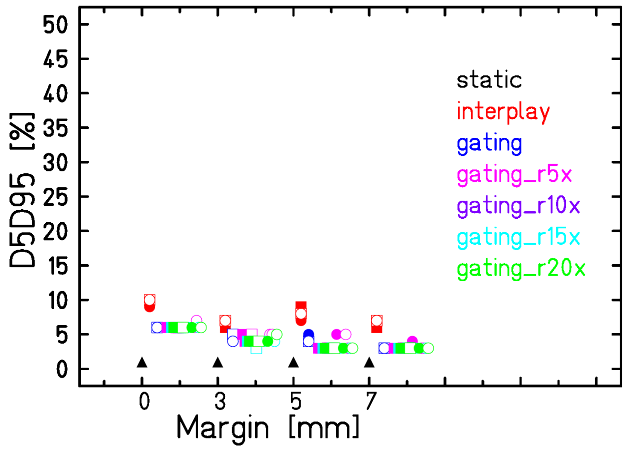
The combination of two motion mitigation techniques, gating and rescanning, would directly apply when not only the respiratory motion but also the heart beat would be compensated for (see chapter XXX). In order to study the outcome of such a delivery, several number of rescans (5, 10, 15 and 20) were applied on the gated irradiation for patient 2 (as an example of a patient with a medium absolute displacement of the target volumes) and patient 9 (with the highest studied absolute displacement). The results can be seen in figure 1.8 and 1.9. The numerical results are shown in appendix XXX.

It becomes obvious that rescanning does further improve the dose delivery, especially regarding dose homogeneity. For patient 2 dose homogeneity values in LPV of 6.79% of the prescribed physical dose of 25 Gy with gating (3 mm margin, lujan motion with 6s period and starting phase of 90°) can be further improved to 4.69% with only five rescans or 3.95% with fifteen rescans. In RPV dose homogeneity values of 4.95% for the same margin and motion can be improved to 4.78% with five rescans and 3.82% with fifteen rescans. For patient 9 the dose homogeneity value of 5.01% for LPV with 3mm margin and lujan motion period of 6s and starting phase of 90° can be improved to 3.83% with only five rescans. For the RPV dose homogeneity of 4.42% with the same margin and motion results to 3.94% with five rescans.

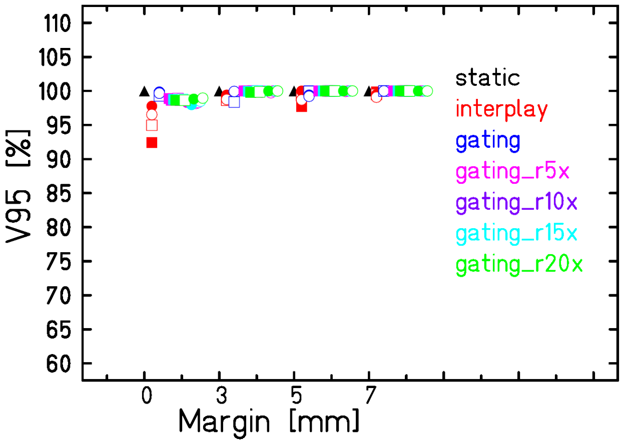
It can be concluded that especially patients with a large motion amplitude, and hence an increased residual motion inside the gating window, can benefit from an overlay of rescanning as a second motion mitigation technique. A small number of rescans, e.g. five, is already sufficient to yield an improved dose homogeneity. As not only respiration but also heart beat needs to be compensated for when irradiating target volumes in the heart (see chapter XXX), the presented combination of motion mitigation techniques is feasible and adequate.



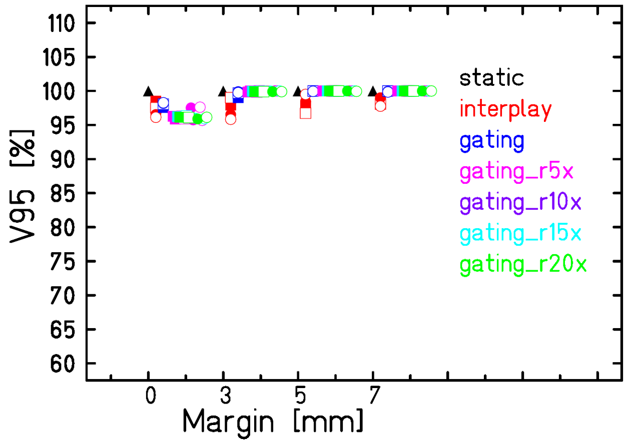
(a) D5-D95: LPV



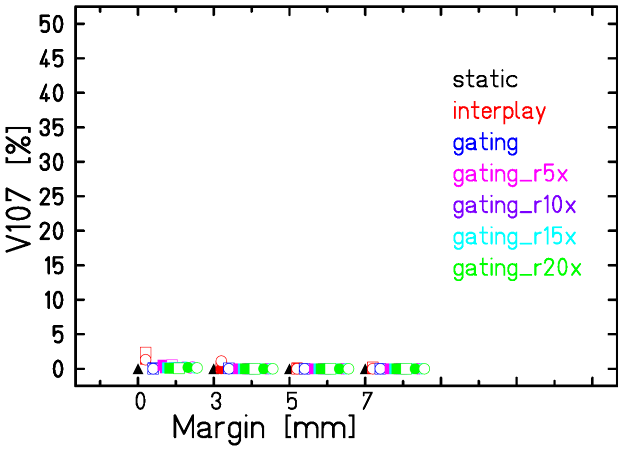
(b) D5-D95: RPV



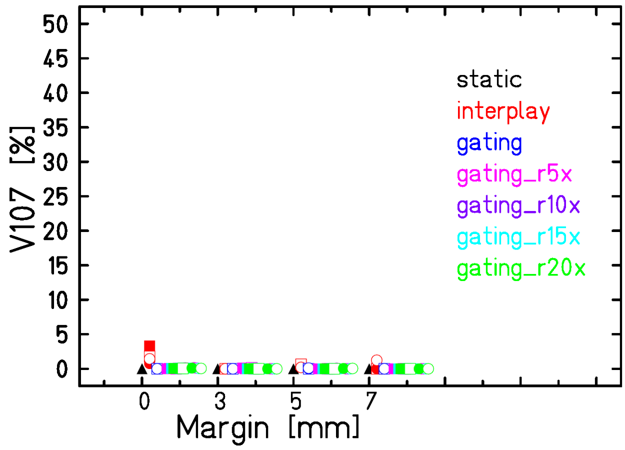
(c) V95: LPV



(d) V95: RPV

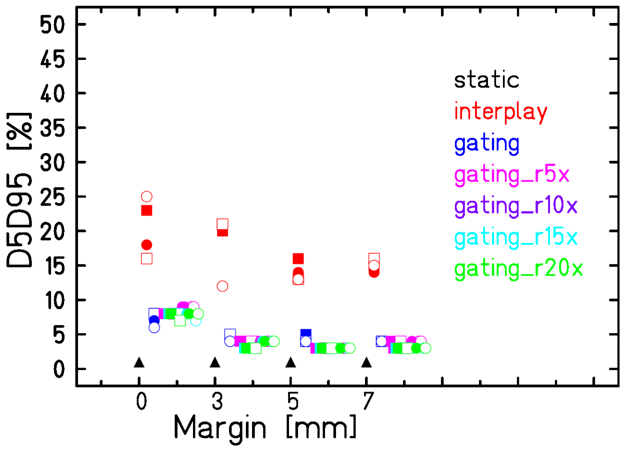


(e) V107: LPV

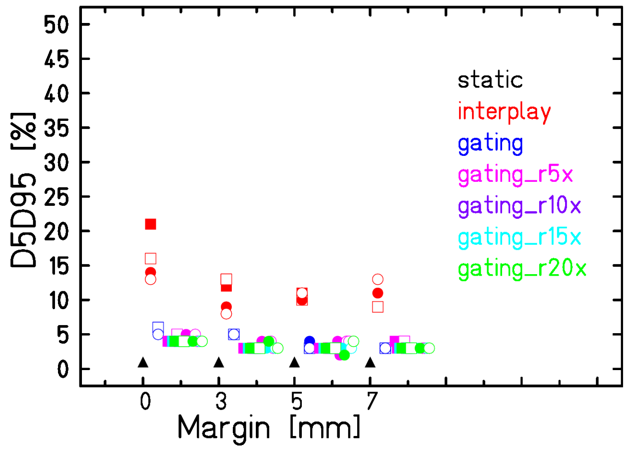


(f) V107: RPV

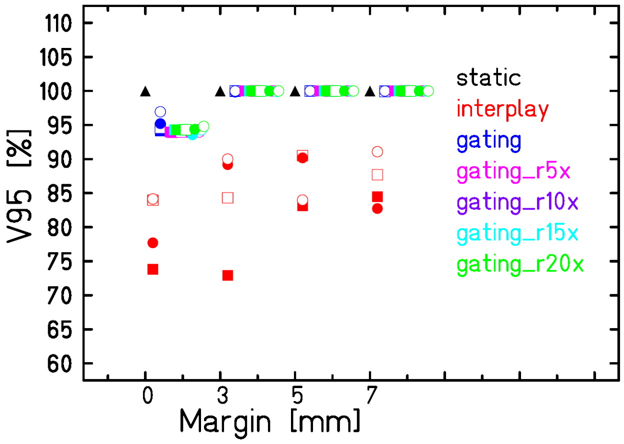
Figure 1.8: Patient 2: Dose analysis parameters for LPV (left column) and RPV (right column). Besides static (black), interplay (red) and gating (blue) also different rescan numbers on the gated irradiation were applied (5 rescans, 10 rescans, 15 rescans and 20 rescans). The results are compared for four different motions (see figure 1.11 - 1.19) and different safety margins.



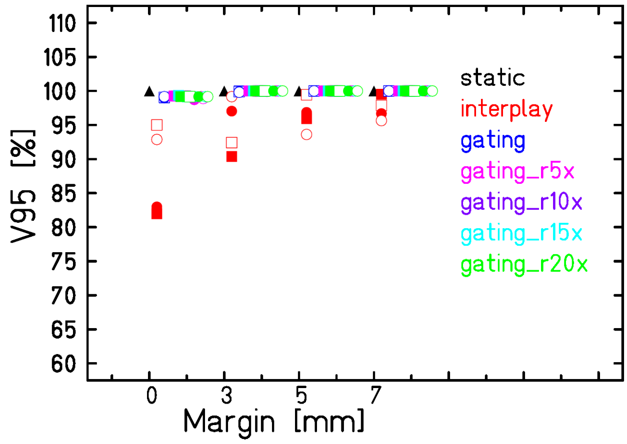
(a) D5-D95: LPV



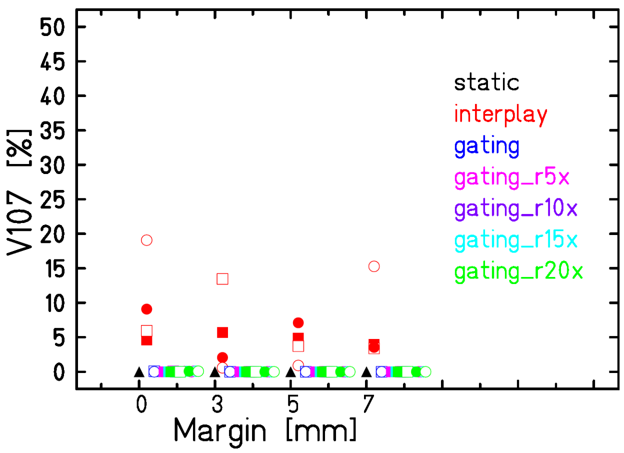
(b) D5-D95: RPV



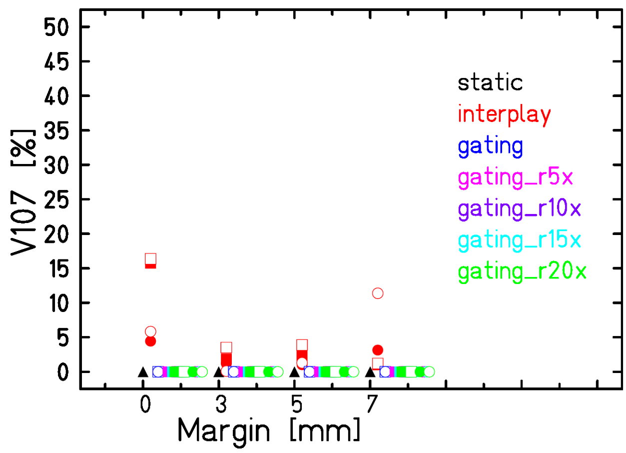
(c) V95: LPV



(d) V95: RPV



(e) V107: LPV



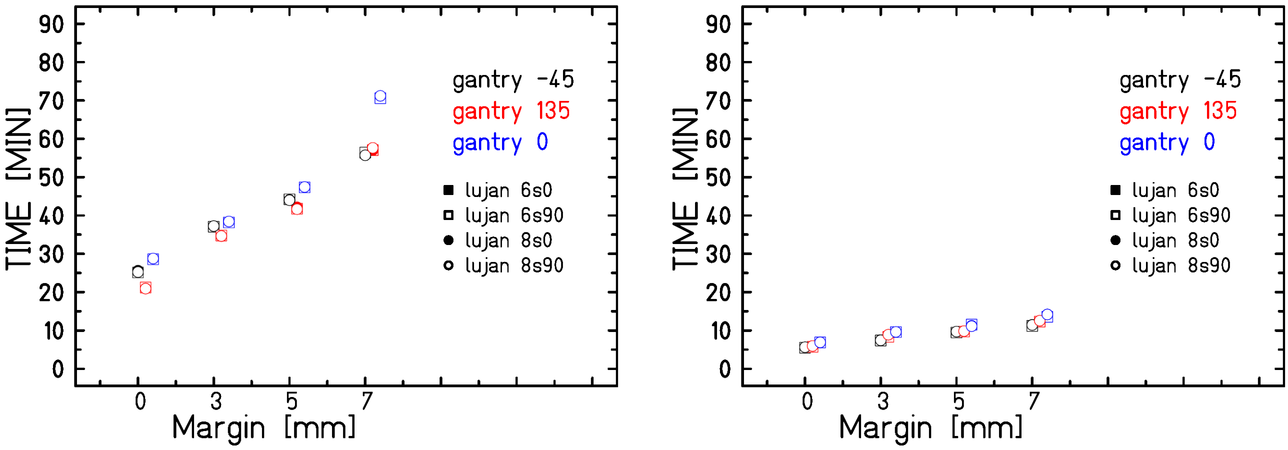
(f) V107: RPV

Figure 1.9: Patient 9: Dose analysis parameters for LPV (left column) and RPV (right column). Besides static (black), interplay (red) and gating (blue) also different rescan numbers on the gated irradiation were applied (5 rescans, 10 rescans, 15 rescans and 20 rescans). The results are compared for four different motions (see figure 1.11 - 1.19) and different safety margins.

Irradiation time

One of the disadvantages of gating as motion mitigation technique is that the irradiation time is increased depending on the used gating window size. When a gating window of roughly 30% is used, like in this case, the irradiation is prolonged by a factor of three compared to the static irradiation. In figure 1.10 the needed irradiation time for the gated irradiation of LPV and RPV in patient 2 is shown for different safety margins and motion patterns. The duration for each beam entry channel (gantry angle of -45°, 135° and 0°) is plotted individually. On the left side the duration of an irradiation with a small minimal particle number (11.000 particles) is shown, while on the right side an irradiation with a higher minimal particle number (55.000 particles) is displayed.

It can be seen that the needed irradiation time increases with the used safety margin as the to irradiated volume increases. Furthermore the irradiation time is independent of the motion pattern but varies depending on the used beam entry channel. While the low intensity irradiation can take up to 120 minutes (for safety margin of 3mm), the overall duration can be reduced to only 30 minutes (for safety margin of 3mm) for the irradiation with a higher intensity. It should be noted that this is the gating time for the respiratory motion alone and the overall treatment time will thus be prolonged, as cardiac motion is not yet compensated for.



(a) Patient 2: smaller intensity (b) Patient 2: higher intensity

Figure 1.10: Irradiation time for gating for patient 2 for different intensities (Nmin = 11.000 (left) and Nmin = 55.000 (right)), different safety margins, underlying motion patterns and beam entry channels.

1.3 Discussion

In this chapter the influence of respiratory motion on the PVs was studied and treatment planning studies with gating as motion mitigation technique were carried out. Respiration was found to be an important motion component for the treatment of cardiac volumes. Recent studies in the cardiology community also indicate that real time compensation of breathing displacement would even be beneficial for catheter ablation [Kum12] [Frie12].

Different studies on the influence of respiration on the PV motion exist as they are of interest for image guided ablation procedures. Thereby relative displacements (like deformation or splaying of the PVs) and absolute motion (translational and rotation) are distinguished. Noseworthy et al. [Nos05] studied the relative changes in the PV anatomy during the breathing cycle. They thereby investigated the changing branching angle between the inferior and superior LPV (LIPV, LSPV) and RPV (RIPV, RSPV), respectively. They stated that the PV splay during inspiration (branching angle of RPVs increased from $(40 \pm 10)^\circ$ to $(60 \pm 15)^\circ$ in inspiration and for LPVs from $(50 \pm 11)^\circ$ to $(62 \pm 13)^\circ$ in inspiration). Furthermore they found a significant reduction in the diameter of the RIPV and RSPV during inspiration. Ector et al. [Ect08] on the other hand stated that they only found a slight, but significant diameter reduction in the RIPV. In their paper they furthermore studied the absolute translational motion. Their patient cohort had a mean diaphragmatic movement of (35 ± 16)mm for the right diaphragm, resulting in an absolute mean displacement for both LPV and RPV of (19.1 ± 8.6)mm. The mean inferior motion was stated to (14.6 ± 7.7)mm, in anterior direction to (9.7 ± 7.6)mm and the smallest motion direction was the leftward direction with (0.4 ± 3.8)mm. Comparing motion patterns between veins the LPVs were found to move less in anterior direction then the RPVs, but did not differ significantly in other directions. They found a strong association between diaphragmatic motion and inferior PV motion.

In the here studied patient cohort of lung cancer patients a much smaller mean absolute displacement of the pulmonary veins was found over all patients with (6.76 ± 3.57)mm for LPV and (6.76 ± 2.51) for RPV. The SI motion was found to (-6.41 ± 3.80)mm and (-6.57 ± 2.42)mm for RPV, respectively. In AP direction the mean amplitude for all patients was found to (-0.81 ± 0.54)mm for LPV and (-0.94 ± 0.84) for RPV, which corresponds to the findining by Ector et al. that the LPV move less in anterior direction than the RPV. For LR direction a mean displacement of (-0.93 ± 0.89) of LPV and (0.48 ± 1.02)mm of RPV was found over all patients. Contrary to Ector et al. a significant difference in the motion of the LPV compared to RPV was hence found in LR. A strong correlation between diaphragm motion and PV displacement was only found in the RPV ($r=0.79$, $p<0.05$). Even though a similar result was expected for the LPV, no correlation was observed here. It is unclear if this is due to location of the ablation site or the underlying lung cancer patient data in comparison to AF patient data sets.

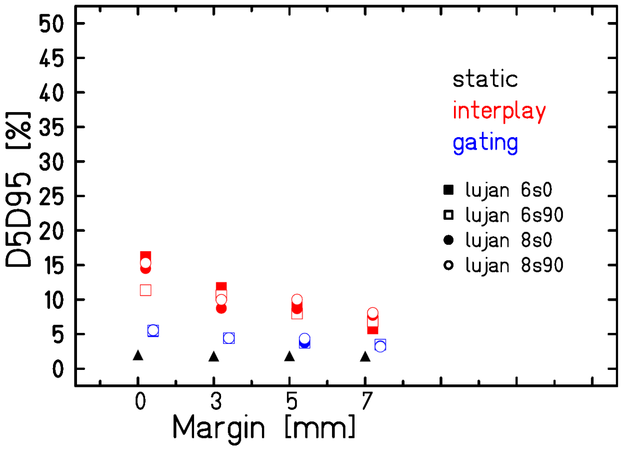
Recent studies in the cardiology community [Kum12] concluded that also for catheter ablation respiration plays an important role as it may reduce the catheter tip contact force. Consideration of respiratory motion is thus recommended. Besides ventilation and apnea, Friedmann [Frie12] also states that jet ventilation or breath-hold might be adequate strategies for catheter ablation. While the latter may also be options for a non-invasive treatment of atrial fibrillation with a scanned carbon ion beam, gating was studied as a motion mitigation technique in the here presented work. In irradiation of cardiac volumes in the animal studies carried out at CyberHeart and at the Universitätsklinikum Schleswig-Holstein in Lübeck different approaches were used. While Blanck et al. [Bla13] used an ITV approach for the respiratory motion, Sharma et al. [Sha10] tracked the respiration with the underlying CyberKnife Synchrony software (see Introduction, section XXX). For particle therapy tracking is not feasible yet as no fast and precise real-time internal motion monitoring including particle range information exists. A simple enlargement of internal margins to produce an ITV for respiration was withdrawn due to expected high dose deposition in critical OAR close to the target sites (see chapter XXX). Gating offers the advantage of a currently technical feasibility while keeping the dose to the normal tissue relatively small. Nevertheless it leads to a prolongation of the treatment time. With a high intensity of 55.000 minimum particles a duration of only 30 minutes could however be achieved (patient 2, safety margin of 3mm). This already offers a reduced treatment time compared to the results by Sharma et al. where a treatment time of one to two hours was estimated.

Concerning the dose deposition with gating compared to interplay it can be concluded that gating yields good dose coverage. The V95 values were higher than 99% for all target sites with safety margin of 3mm or more and higher than 95% in all cases with no safety margin (minimum of 95.21% in patient 9 for LPV, no safety margin and motion with period of 8s and starting phase of 0°).The V107 values were all smaller than 0.1% (maximum of 0.1% for patient 2, RPV, in case of 5mm margin and motion with period of 8s and starting phase of 90°). Hence an acceptable dose coverage could be achieved. The dose homogeneity did not exceed 9.18% without safety margin (patient 5, LPV, no safety margin and motion with period of 8s and starting phase of 90°). With safety margin, the D5-D95 value did not exceed 8%. An additional safety margin is thus beneficial to guarantee a robust and successful treatment delivery. However, an extension of the target volume due to safety margins always results in more dose to the normal tissue and to potential critical OARs. A limited safety margin of 3mm would offer the benefit of improved treatment outcome while keeping the irradiated volume low (see also chapter XXX).

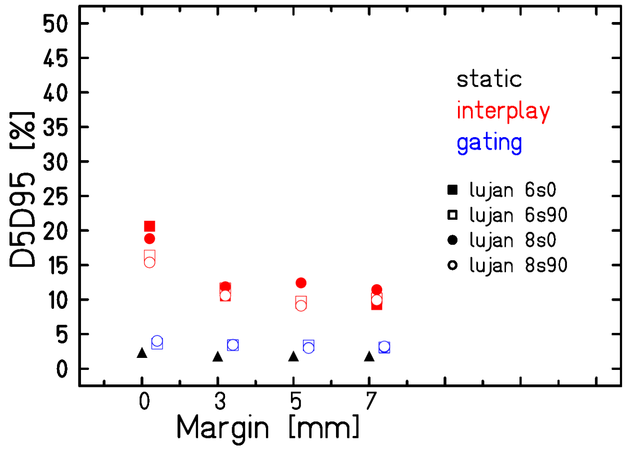
It can be concluded that gating yields improved dose coverage (under and over dosage) and better dose homogeneity compared to interplay in all studied patient cases, motion patterns and for all safety margins. It can thus be an adequate motion mitigation technique for the irradiation of PVs under influence of respiratory motion.

Rescanning within the gating window could further improve the results for dose homogeneity as it reduces the influence of residual motion inside the gating window. Especially patients with a large displacement of the ablation site due to respiration profit from this additional motion mitigation technique. That way the dose homogeneity in the LPV of patient 9 (large motion amplitude) could be reduced from 5.01% (safety margin of 3mm and lujan motion with period 6s and 90° starting phase) to 3.83% with 5 rescans. A small number of rescans (e.g. five) is hence sufficient to improve the results. As rescanning is a potential technique when compensating for displacements due to heart beat (see chapter XXX), the combination of these two methods would be automatically feasible.

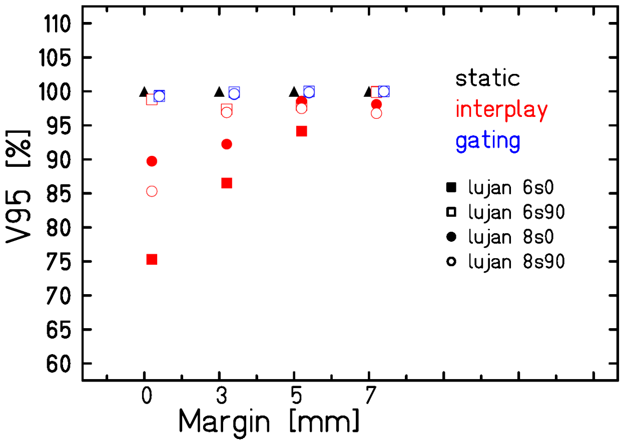
for Appendix



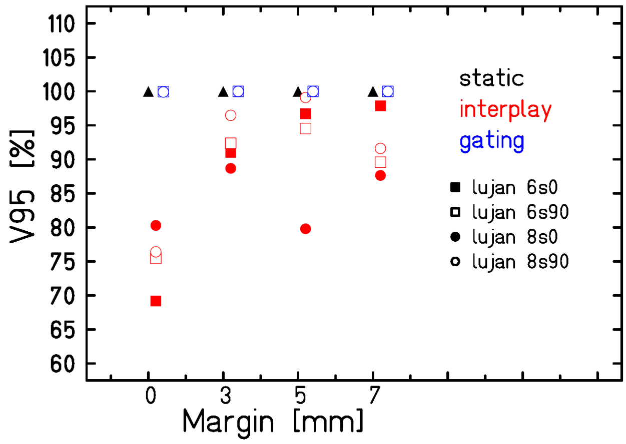
(a) D5-D95: LPV



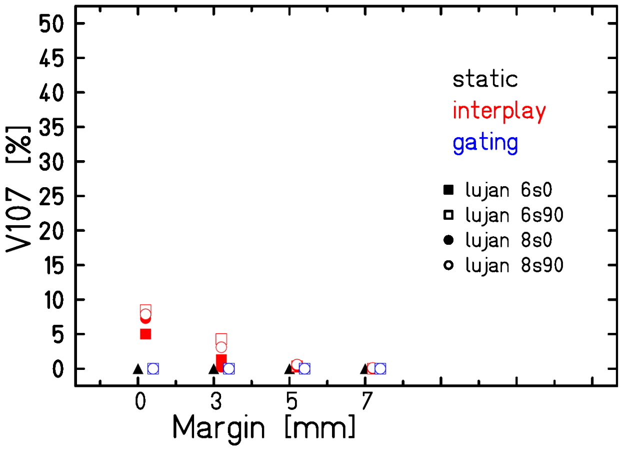
(b) D5-D95: RPV



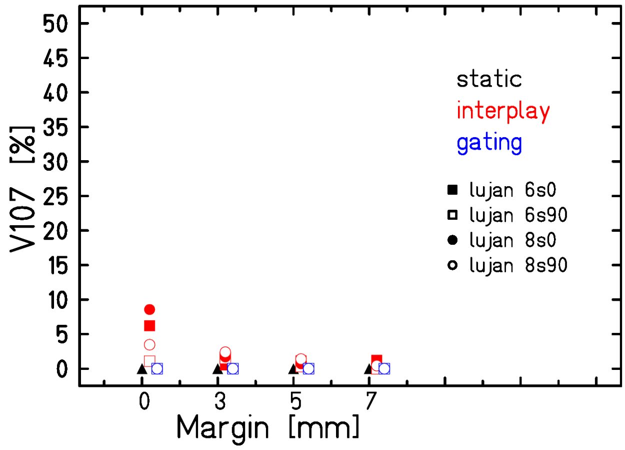
(c) V95: LPV



(d) V95: RPV

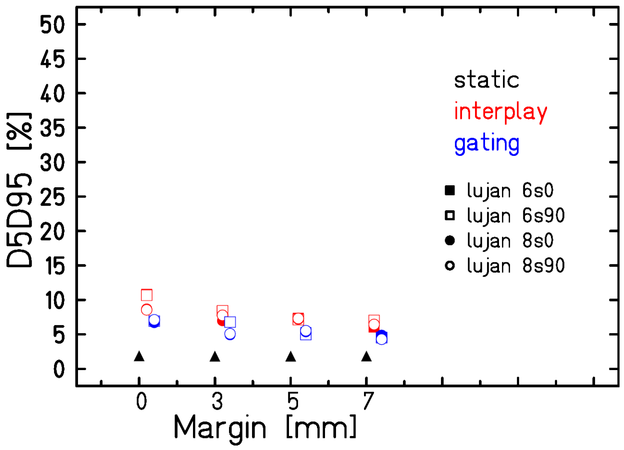


(e) V107: LPV

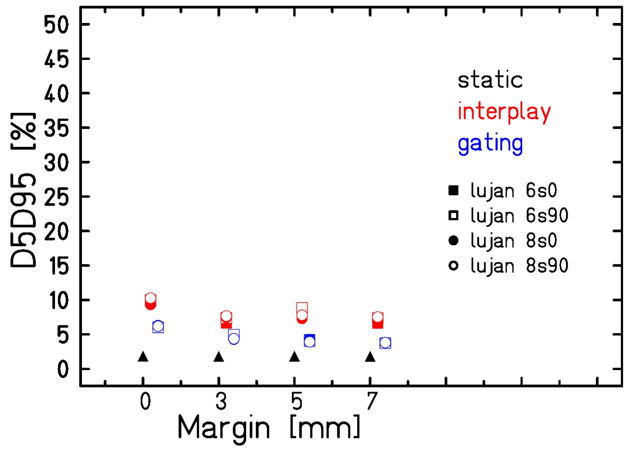


(f) V107: RPV

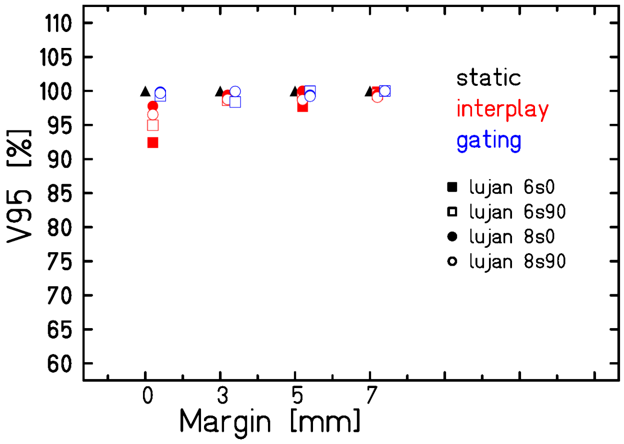
Figure 1.11: Patient 1: Dose analysis parameters D5-D95 (dose homogeneity, first row), V95 (dose coverage, middle row) and V107 (over dosage, last row). The LPV (left column) and RPV (right column) were studied seperately. Static (black) as well as interplay (red) and gating (blue) are compared for four different motions and different safety margins.



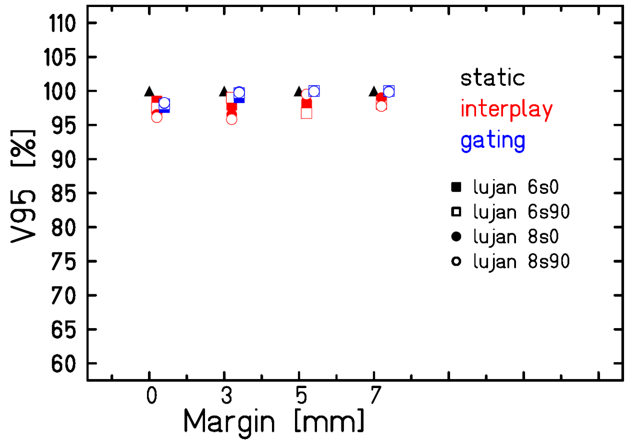
(a) D5-D95: LPV



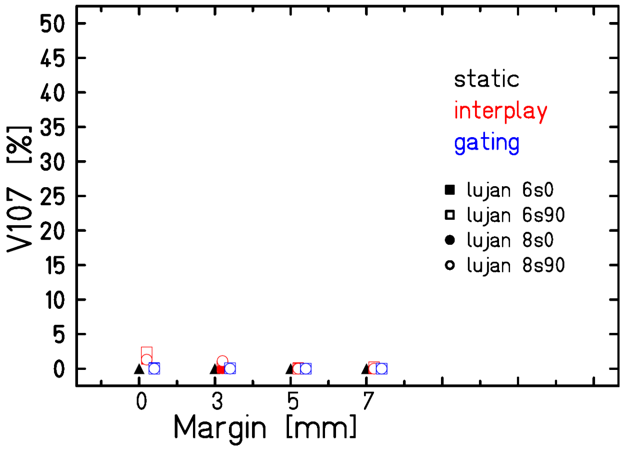
(b) D5-D95: RPV



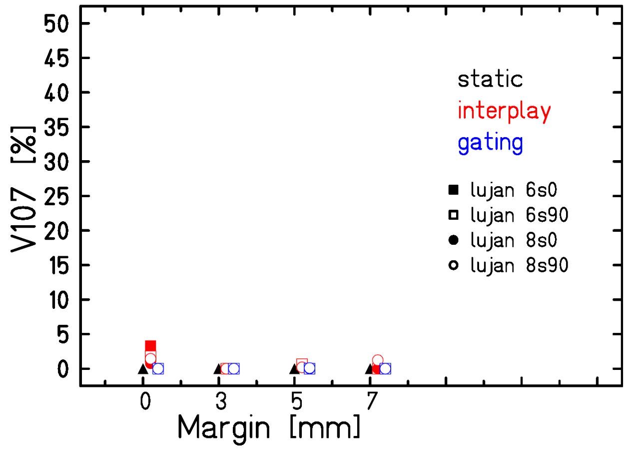
(c) V95: LPV



(d) V95: RPV

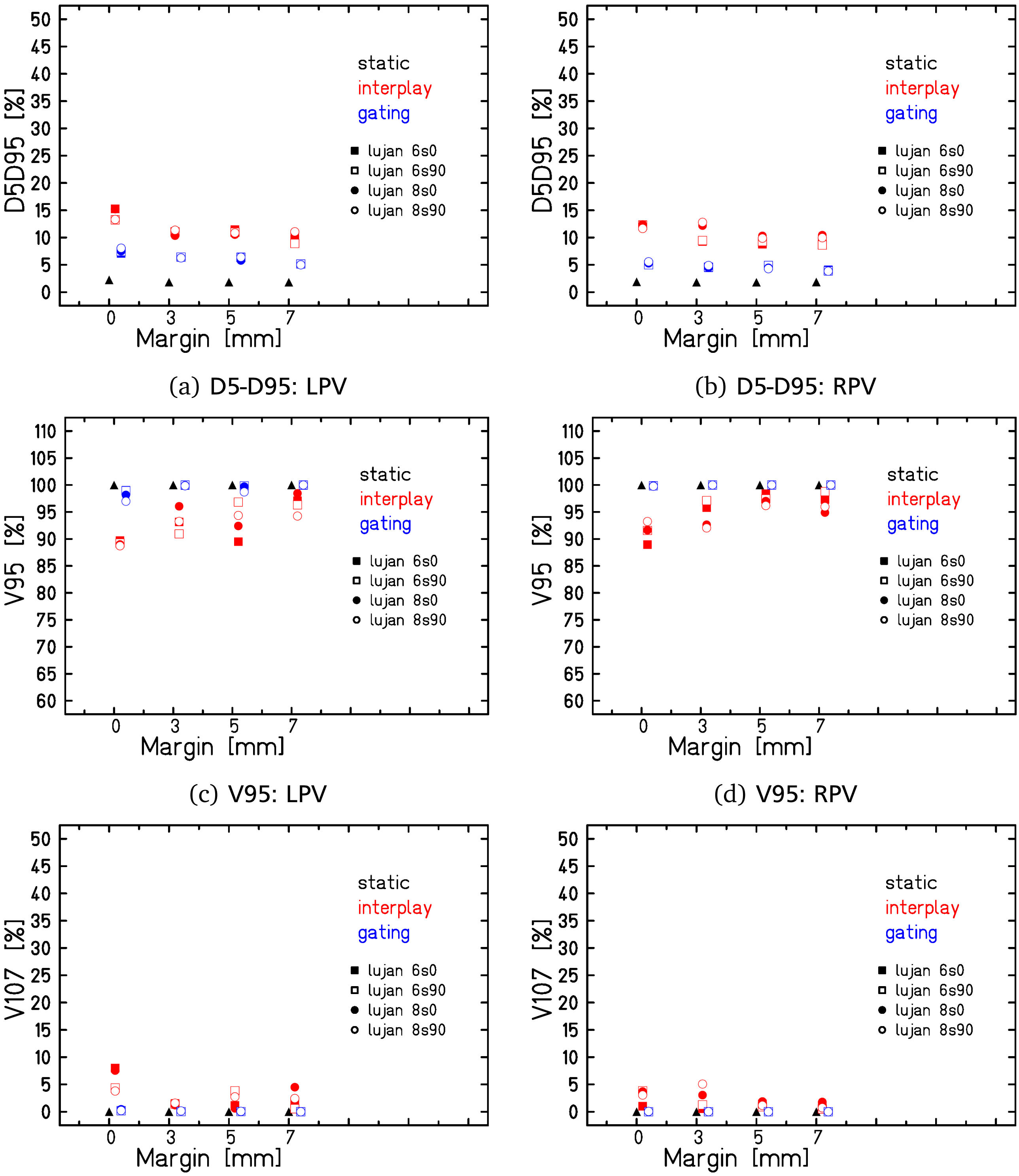


(e) V107: LPV



(f) V107: RPV

Figure 1.12: Patient 2: Dose analysis parameters D5-D95 (dose homogeneity, first row), V95 (dose coverage, middle row) and V107 (over dosage, last row). The LPV (left column) and RPV (right column) were studied seperately. Static (black) as well as interplay (red) and gating (blue) are compared for four different motions and different safety margins.

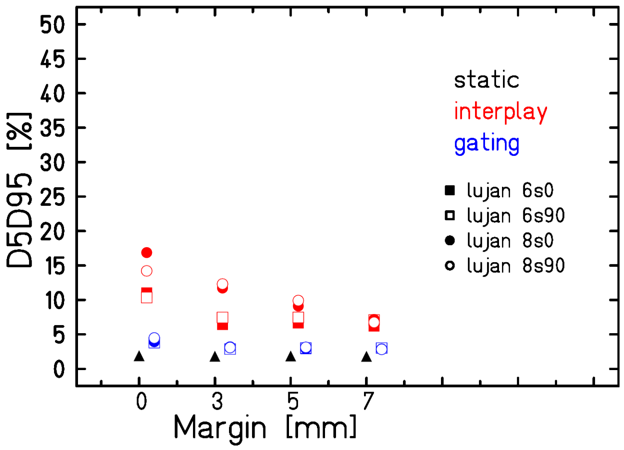


(a) D5-D95: LPV (b) D5-D95: RPV

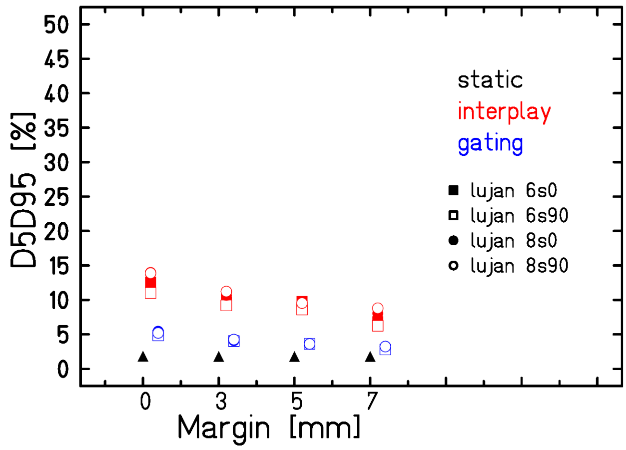
(c) V95: LPV (d) V95: RPV

(e) V107: LPV (f) V107: RPV

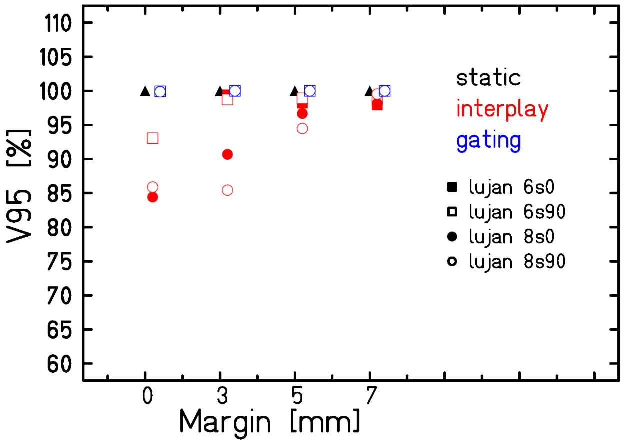
Figure 1.13: Patient 3: Dose analysis parameters D5-D95 (dose homogeneity, first row), V95 (dose coverage, middle row) and V107 (over dosage, last row). The LPV (left column) and RPV (right column) were studied seperately. Static (black) as well as interplay (red) and gating (blue) are compared for four different motions and different safety margins.



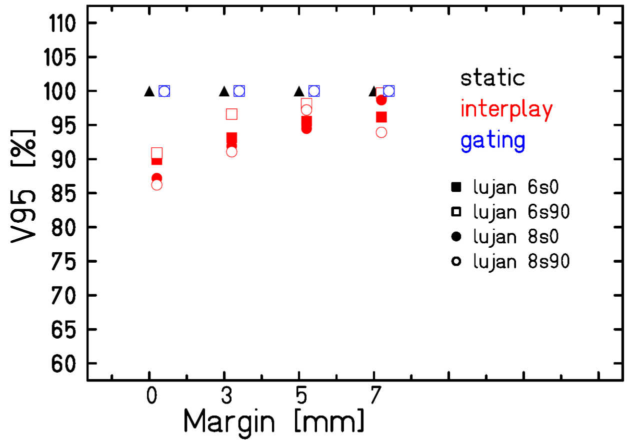
(a) D5-D95: LPV



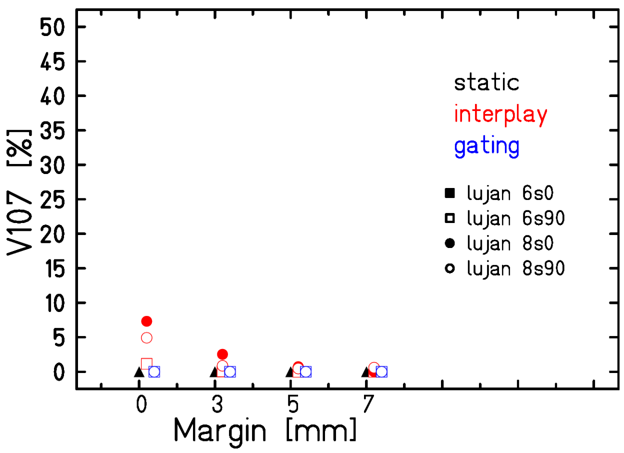
(b) D5-D95: RPV



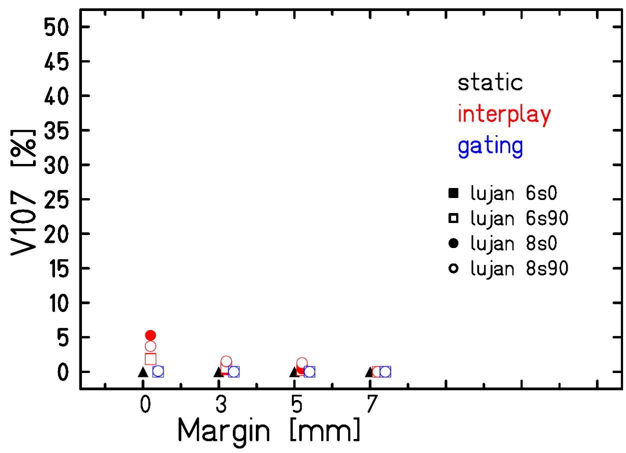
(c) V95: LPV



(d) V95: RPV

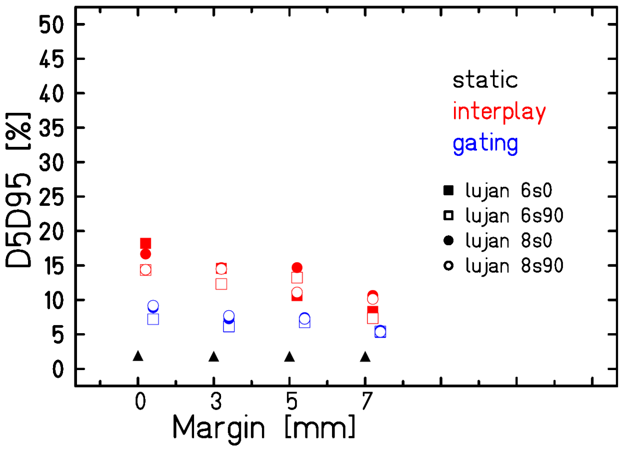


(e) V107: LPV

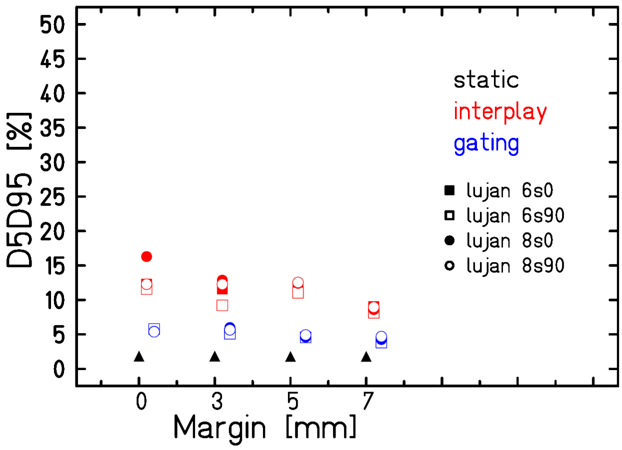


(f) V107: RPV

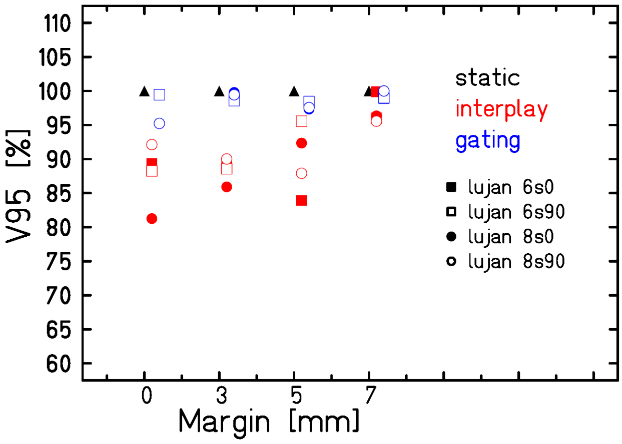
Figure 1.14: Patient 4: Dose analysis parameters D5-D95 (dose homogeneity, first row), V95 (dose coverage, middle row) and V107 (over dosage, last row). The LPV (left column) and RPV (right column) were studied seperately. Static (black) as well as interplay (red) and gating (blue) are compared for four different motions and different safety margins.



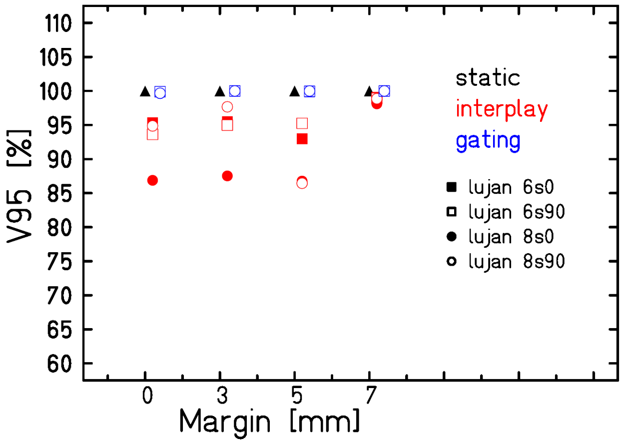
(a) D5-D95: LPV



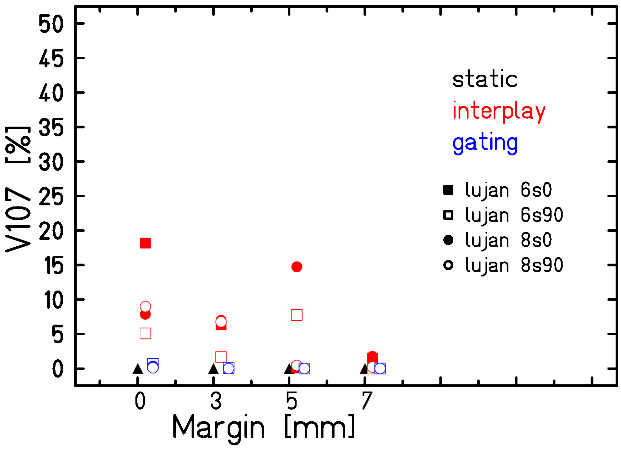
(b) D5-D95: RPV



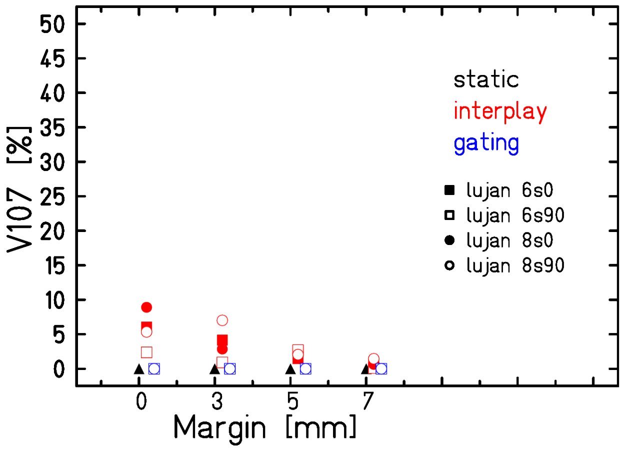
(c) V95: LPV



(d) V95: RPV

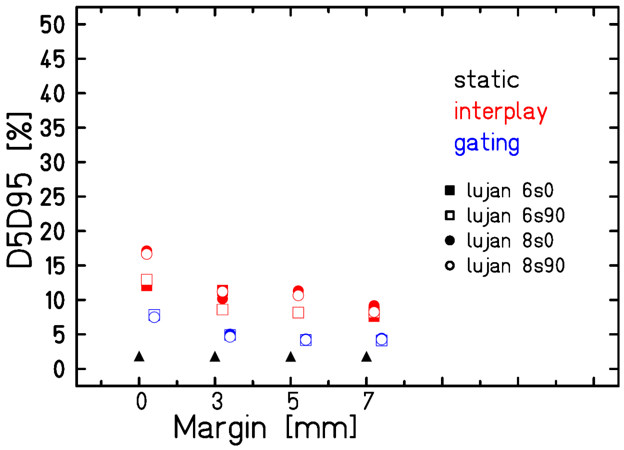


(e) V107: LPV

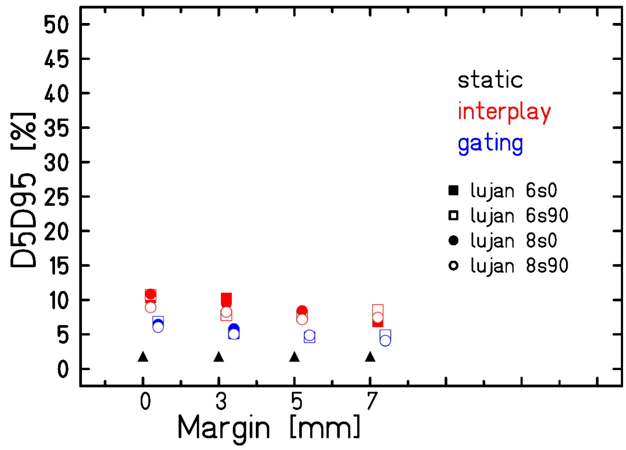


(f) V107: RPV

Figure 1.15: Patient 5: Dose analysis parameters D5-D95 (dose homogeneity, first row), V95 (dose coverage, middle row) and V107 (over dosage, last row). The LPV (left column) and RPV (right column) were studied seperately. Static (black) as well as interplay (red) and gating (blue) are compared for four different motions and different safety margins.



(a) D5-D95: LPV



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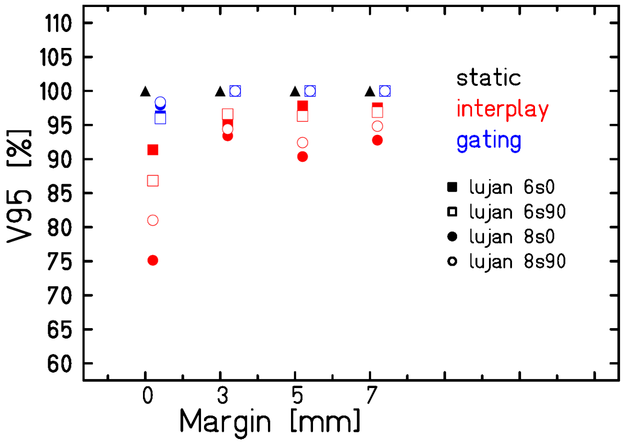
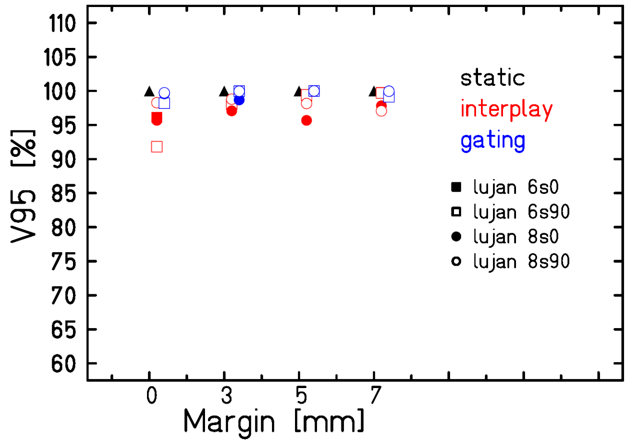
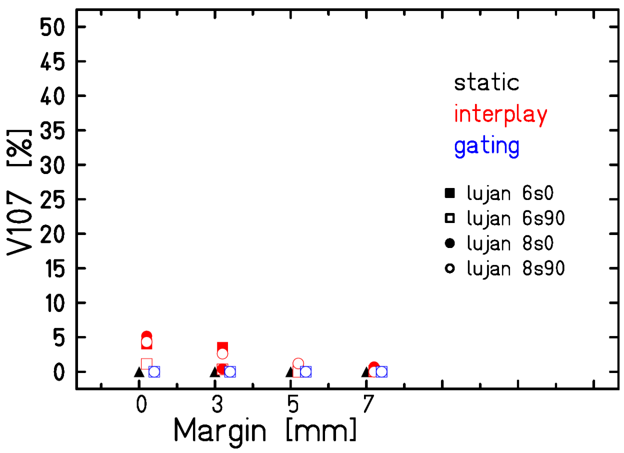


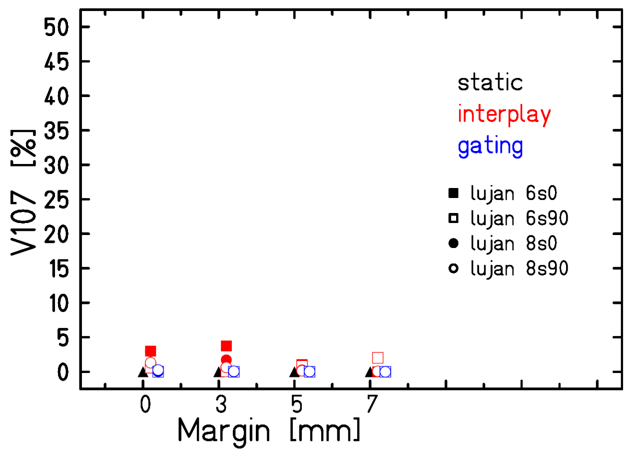
(c) V95: LPV



(d) V95: RPV

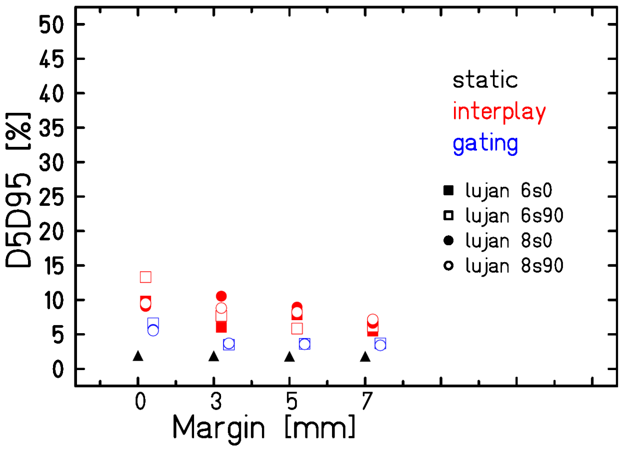


(e) V107: LPV

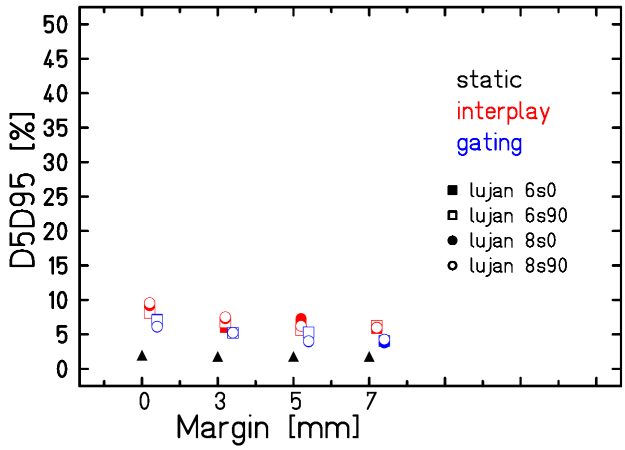


(f) V107: RPV

Figure 1.16: Patient 6: Dose analysis parameters D5-D95 (dose homogeneity, first row), V95 (dose coverage, middle row) and V107 (over dosage, last row). The LPV (left column) and RPV (right column) were studied seperately. Static (black) as well as interplay (red) and gating (blue) are compared for four different motions and different safety margins.



(a) D5-D95: LPV



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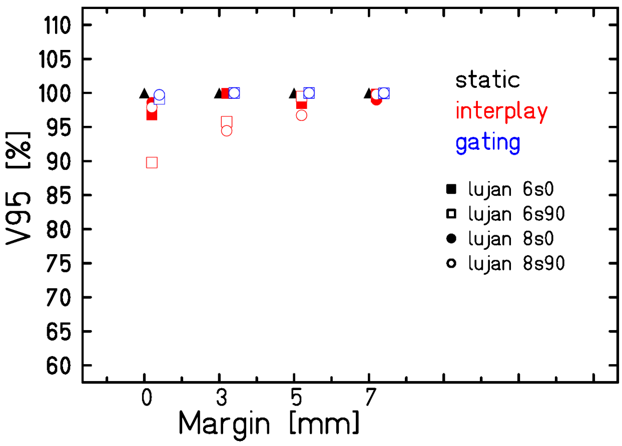
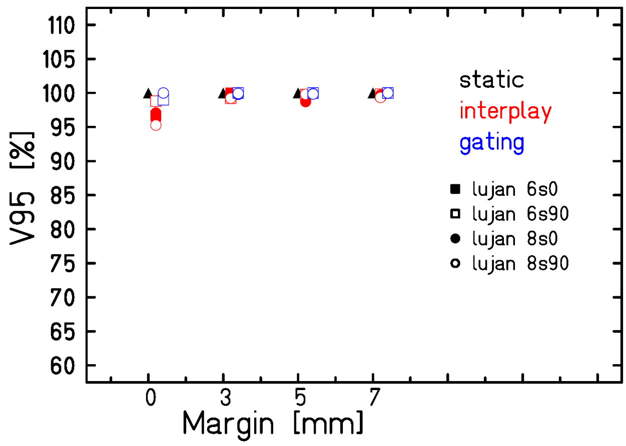
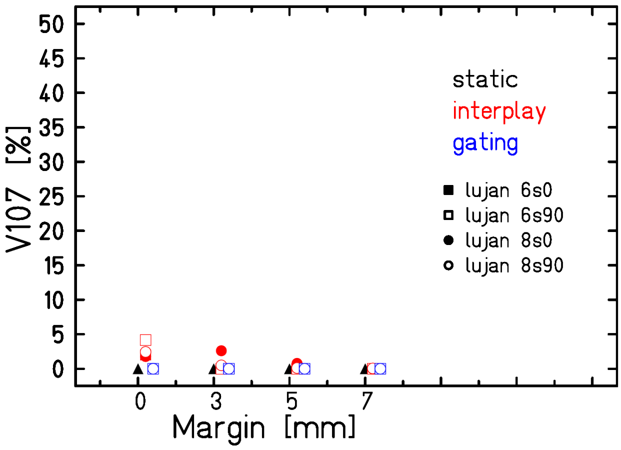


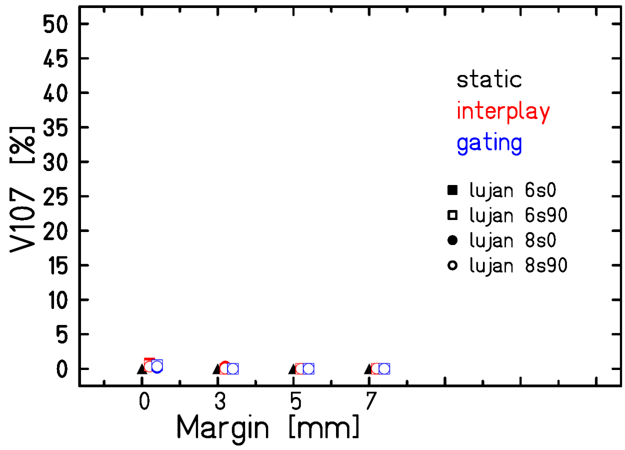
(c) V95: LPV



(d) V95: RPV

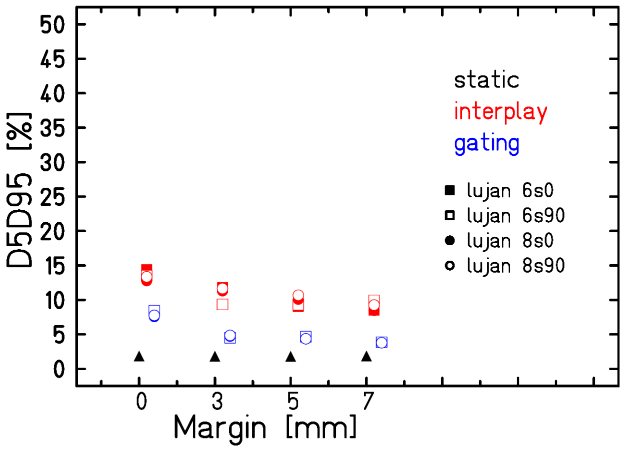


(e) V107: LPV

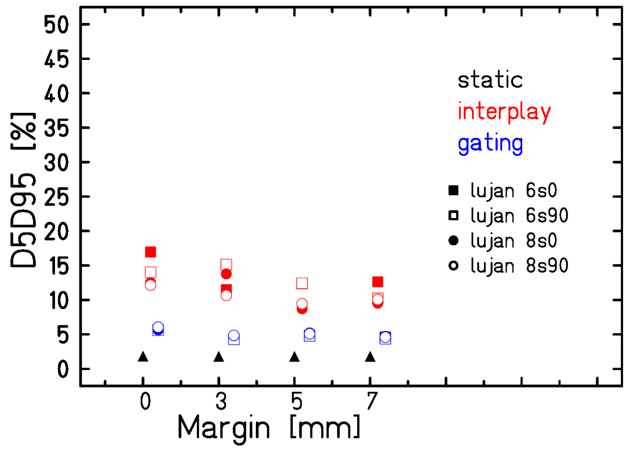


(f) V107: RPV

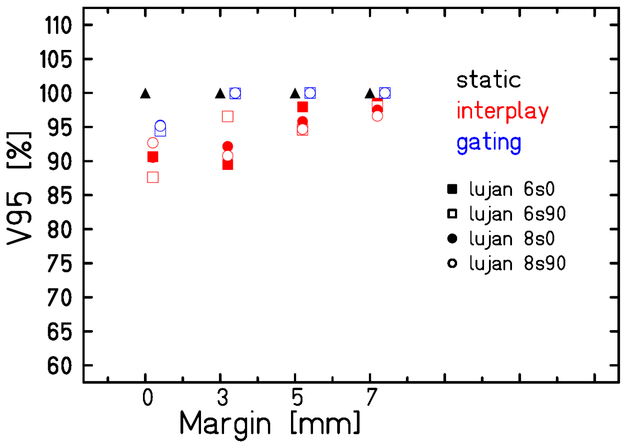
Figure 1.17: Patient 7: Dose analysis parameters D5-D95 (dose homogeneity, first row), V95 (dose coverage, middle row) and V107 (over dosage, last row). The LPV (left column) and RPV (right column) were studied seperately. Static (black) as well as interplay (red) and gating (blue) are compared for four different motions and different safety margins.



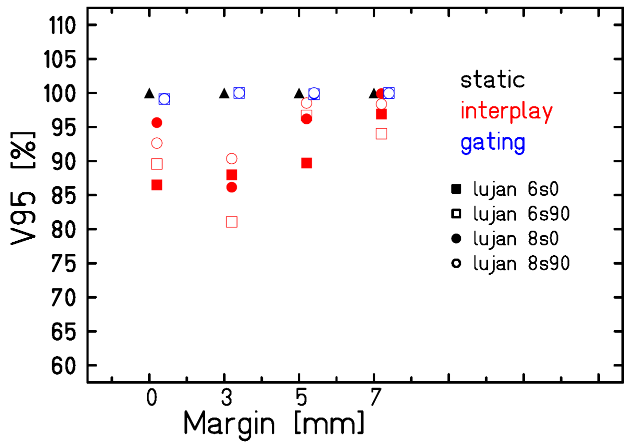
(a) D5-D95: LPV



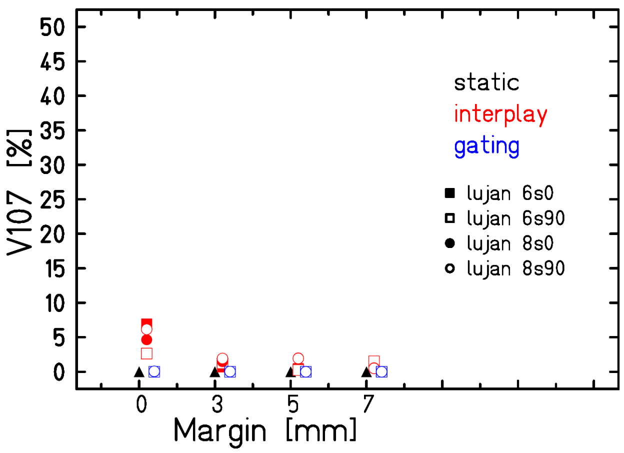
(b) D5-D95: RPV



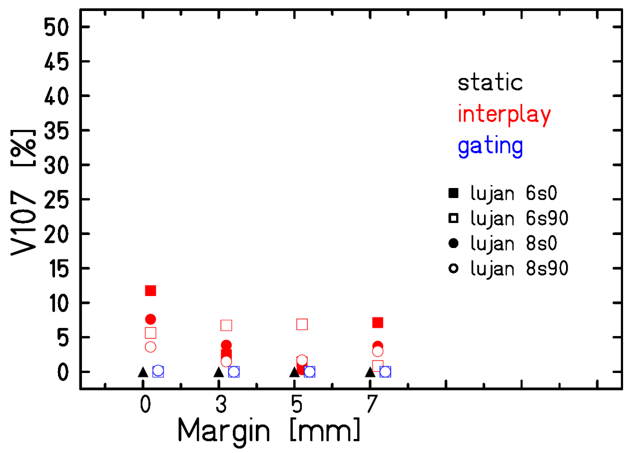
(c) V95: LPV



(d) V95: RPV

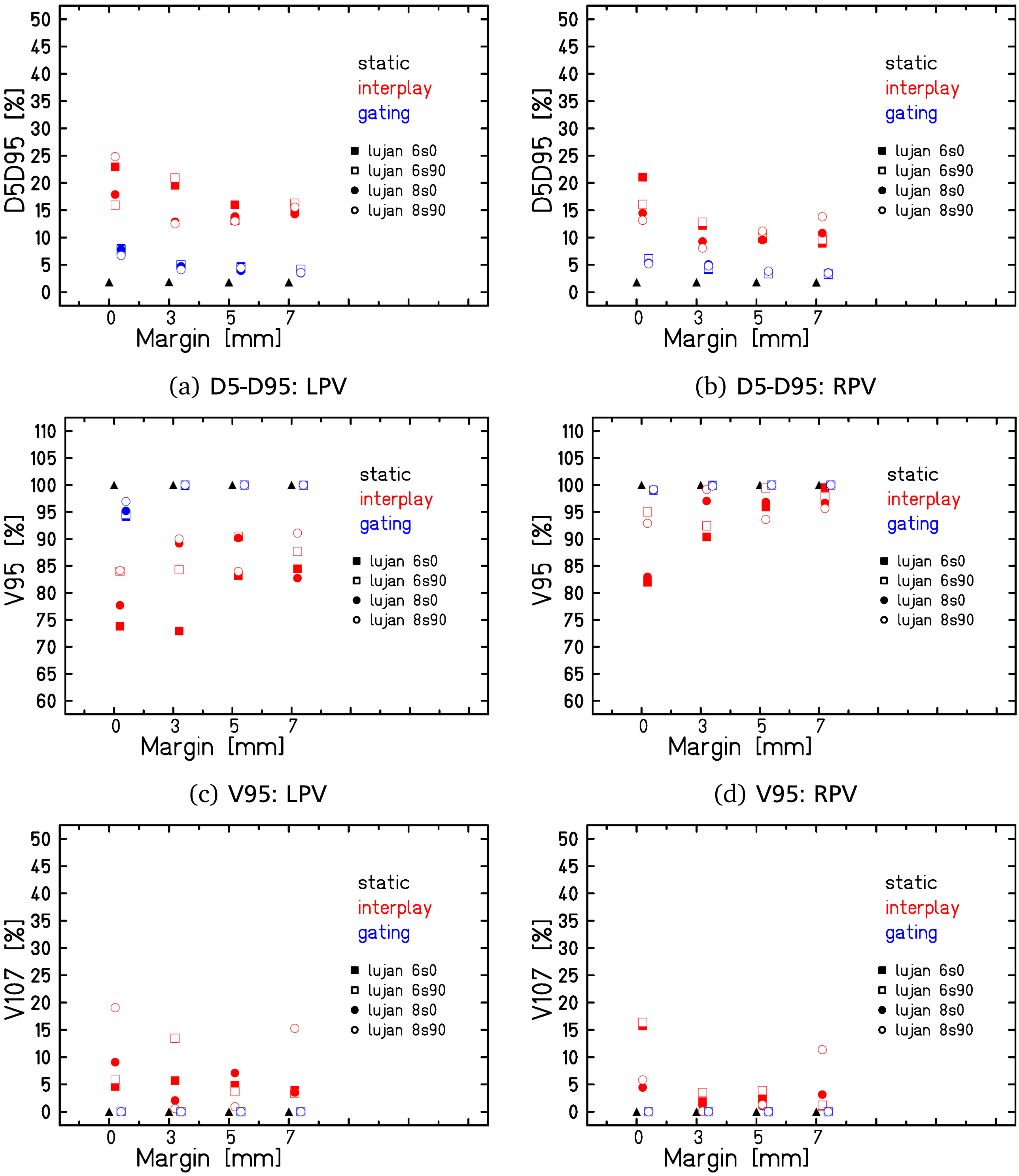


(e) V107: LPV



(f) V107: RPV

Figure 1.18: Patient 8: Dose analysis parameters D5-D95 (dose homogeneity, first row), V95 (dose coverage, middle row) and V107 (over dosage, last row). The LPV (left column) and RPV (right column) were studied seperately. Static (black) as well as interplay (red) and gating (blue) are compared for four different motions and different safety margins.



(a) D5-D95: LPV

(b) D5-D95: RPV

(c) V95: LPV

(d) V95: RPV

(e) V107: LPV

(f) V107: RPV

Figure 1.19: Patient 9: Dose analysis parameters D5-D95 (dose homogeneity, first row), V95 (dose coverage, middle row) and V107 (over dosage, last row). The LPV (left column) and RPV (right column) were studied seperately. Static (black) as well as interplay (red) and gating (blue) are compared for four different motions and different safety margins.

Table 1.5: Patient 1, LPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	2.00	100.00	0.00
STATIC	-	-	3mm	1.83	100.00	0.00
STATIC	-	-	5mm	1.86	100.00	0.00
STATIC	-	-	7mm	1.82	100.00	0.00
INTERPLAY	6s	0	0mm	16.23	75.30	5.01
INTERPLAY	6s	90	0mm	11.37	98.81	8.47
INTERPLAY	8s	0	0mm	14.51	89.74	7.28
INTERPLAY	8s	90	0mm	15.31	85.32	7.88
INTERPLAY	6s	0	3mm	11.73	86.52	1.31
INTERPLAY	6s	90	3mm	10.60	97.37	4.30
INTERPLAY	8s	0	3mm	8.75	92.24	0.24
INTERPLAY	8s	90	3mm	9.98	96.90	3.10
INTERPLAY	6s	0	5mm	8.91	94.15	0.24
INTERPLAY	6s	90	5mm	7.98	97.97	0.36
INTERPLAY	8s	0	5mm	8.69	98.57	0.36
INTERPLAY	8s	90	5mm	10.02	97.49	0.60
INTERPLAY	6s	0	7mm	5.79	100.00	0.00
INTERPLAY	6s	90	7mm	6.86	99.88	0.00
INTERPLAY	8s	0	7mm	7.74	98.09	0.00
INTERPLAY	8s	90	7mm	8.09	96.78	0.12
GATING	6s	0	0mm	5.37	99.40	0.00
GATING	6s	90	0mm	5.53	99.28	0.00
GATING	8s	0	0mm	5.65	99.40	0.00
GATING	8s	90	0mm	5.57	99.28	0.00
GATING	6s	0	3mm	4.41	99.88	0.00
GATING	6s	90	3mm	4.41	99.88	0.00
GATING	8s	0	3mm	4.39	99.52	0.00
GATING	8s	90	3mm	4.43	99.64	0.00
GATING	6s	0	5mm	3.88	100.00	0.00
GATING	6s	90	5mm	3.76	100.00	0.00
GATING	8s	0	5mm	3.77	99.76	0.00
GATING	8s	90	5mm	4.36	99.88	0.00
GATING	6s	0	7mm	3.50	100.00	0.00
GATING	6s	90	7mm	3.47	100.00	0.00
GATING	8s	0	7mm	3.29	100.00	0.00
GATING	8s	90	7mm	3.17	100.00	0.00

Table 1.6: Patient 1, RPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	2.36	100.00	0.00
STATIC	-	-	3mm	1.81	100.00	0.00
STATIC	-	-	5mm	1.85	100.00	0.00
STATIC	-	-	7mm	1.84	100.00	0.00
INTERPLAY	6s	0	0mm	20.62	69.21	6.22
INTERPLAY	6s	90	0mm	16.39	75.47	1.08
INTERPLAY	8s	0	0mm	18.83	80.30	8.57
INTERPLAY	8s	90	0mm	15.38	76.42	3.47
INTERPLAY	6s	0	3mm	10.54	91.03	0.54
INTERPLAY	6s	90	3mm	11.63	92.38	1.49
INTERPLAY	8s	0	3mm	11.86	88.68	1.71
INTERPLAY	8s	90	3mm	10.59	96.48	2.39
INTERPLAY	6s	0	5mm	9.46	96.71	1.13
INTERPLAY	6s	90	5mm	9.72	94.54	0.32
INTERPLAY	8s	0	5mm	12.43	79.80	0.72
INTERPLAY	8s	90	5mm	9.11	99.10	1.40
INTERPLAY	6s	0	7mm	9.29	97.88	1.22
INTERPLAY	6s	90	7mm	10.18	89.59	0.00
INTERPLAY	8s	0	7mm	11.44	87.65	0.50
INTERPLAY	8s	90	7mm	9.92	91.61	0.45
GATING	6s	0	0mm	3.62	99.95	0.00
GATING	6s	90	0mm	3.63	99.95	0.00
GATING	8s	0	0mm	4.02	99.95	0.00
GATING	8s	90	0mm	4.03	99.91	0.00
GATING	6s	0	3mm	3.40	100.00	0.00
GATING	6s	90	3mm	3.40	100.00	0.00
GATING	8s	0	3mm	3.51	100.00	0.00
GATING	8s	90	3mm	3.45	100.00	0.00
GATING	6s	0	5mm	3.40	100.00	0.00
GATING	6s	90	5mm	3.37	100.00	0.00
GATING	8s	0	5mm	3.04	100.00	0.00
GATING	8s	90	5mm	2.98	100.00	0.00
GATING	6s	0	7mm	3.00	100.00	0.00
GATING	6s	90	7mm	3.08	100.00	0.00
GATING	8s	0	7mm	3.09	100.00	0.00
GATING	8s	90	7mm	3.22	100.00	0.00

Table 1.7: Patient 2, LPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	1.89	100.00	0.00
STATIC	-	-	3mm	1.85	100.00	0.00
STATIC	-	-	5mm	1.85	100.00	0.00
STATIC	-	-	7mm	1.86	100.00	0.00
INTERPLAY	6s	0	0mm	10.82	92.42	1.37
INTERPLAY	6s	90	0mm	10.68	94.97	2.35
INTERPLAY	8s	0	0mm	8.70	97.78	1.31
INTERPLAY	8s	90	0mm	8.56	96.54	1.31
INTERPLAY	6s	0	3mm	8.38	98.82	0.07
INTERPLAY	6s	90	3mm	8.41	98.63	0.33
INTERPLAY	8s	0	3mm	6.98	99.41	0.00
INTERPLAY	8s	90	3mm	7.77	98.76	1.11
INTERPLAY	6s	0	5mm	7.34	97.71	0.13
INTERPLAY	6s	90	5mm	7.15	99.28	0.00
INTERPLAY	8s	0	5mm	7.20	100.00	0.13
INTERPLAY	8s	90	5mm	7.32	98.69	0.00
INTERPLAY	6s	0	7mm	6.07	99.87	0.00
INTERPLAY	6s	90	7mm	7.01	99.48	0.20
INTERPLAY	8s	0	7mm	6.40	99.48	0.00
INTERPLAY	8s	90	7mm	6.44	99.08	0.00
GATING	6s	0	0mm	6.96	99.41	0.13
GATING	6s	90	0mm	6.93	99.28	0.00
GATING	8s	0	0mm	6.71	99.87	0.00
GATING	8s	90	0mm	7.12	99.67	0.00
GATING	6s	0	3mm	6.81	98.43	0.07
GATING	6s	90	3mm	6.79	98.37	0.07
GATING	8s	0	3mm	4.94	99.93	0.00
GATING	8s	90	3mm	5.10	99.93	0.00
GATING	6s	0	5mm	5.27	100.00	0.00
GATING	6s	90	5mm	4.98	99.93	0.00
GATING	8s	0	5mm	5.39	99.41	0.00
GATING	8s	90	5mm	5.54	99.22	0.00
GATING	6s	0	7mm	4.60	100.00	0.00
GATING	6s	90	7mm	4.53	100.00	0.00
GATING	8s	0	7mm	4.89	100.00	0.00
GATING	8s	90	7mm	4.30	100.00	0.00

Table 1.8: Patient 2, RPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	1.85	100.00	0.00
STATIC	-	-	3mm	1.82	100.00	0.00
STATIC	-	-	5mm	1.84	100.00	0.00
STATIC	-	-	7mm	1.81	100.00	0.00
INTERPLAY	6s	0	0mm	10.03	98.51	3.32
INTERPLAY	6s	90	0mm	9.87	97.52	1.78
INTERPLAY	8s	0	0mm	9.31	96.53	0.74
INTERPLAY	8s	90	0mm	10.27	96.14	1.44
INTERPLAY	6s	0	3mm	6.64	97.92	0.00
INTERPLAY	6s	90	3mm	7.38	99.01	0.00
INTERPLAY	8s	0	3mm	7.43	96.53	0.00
INTERPLAY	8s	90	3mm	7.67	95.84	0.00
INTERPLAY	6s	0	5mm	8.73	97.77	0.64
INTERPLAY	6s	90	5mm	8.84	96.73	0.64
INTERPLAY	8s	0	5mm	7.29	98.47	0.20
INTERPLAY	8s	90	5mm	7.80	99.50	0.20
INTERPLAY	6s	0	7mm	6.61	98.61	0.00
INTERPLAY	6s	90	7mm	7.38	98.07	0.00
INTERPLAY	8s	0	7mm	7.01	99.01	0.00
INTERPLAY	8s	90	7mm	7.53	97.77	1.24
GATING	6s	0	0mm	6.04	97.57	0.00
GATING	6s	90	0mm	6.02	98.07	0.00
GATING	8s	0	0mm	6.32	98.17	0.00
GATING	8s	90	0mm	6.19	98.27	0.00
GATING	6s	0	3mm	4.87	99.01	0.00
GATING	6s	90	3mm	4.95	99.70	0.00
GATING	8s	0	3mm	4.27	99.90	0.00
GATING	8s	90	3mm	4.37	99.75	0.00
GATING	6s	0	5mm	4.26	100.00	0.00
GATING	6s	90	5mm	4.05	100.00	0.00
GATING	8s	0	5mm	4.28	99.95	0.00
GATING	8s	90	5mm	3.92	99.95	0.10
GATING	6s	0	7mm	3.70	100.00	0.00
GATING	6s	90	7mm	3.73	100.00	0.00
GATING	8s	0	7mm	3.81	99.95	0.00
GATING	8s	90	7mm	3.81	99.85	0.00

Table 1.9: Patient 3, LPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	2.24	100.00	0.00
STATIC	-	-	3mm	1.84	100.00	0.00
STATIC	-	-	5mm	1.82	100.00	0.00
STATIC	-	-	7mm	1.82	100.00	0.00
INTERPLAY	6s	0	0mm	15.27	89.72	8.00
INTERPLAY	6s	90	0mm	13.25	89.24	4.35
INTERPLAY	8s	0	0mm	15.22	88.98	7.56
INTERPLAY	8s	90	0mm	13.31	88.72	3.80
INTERPLAY	6s	0	3mm	10.89	93.14	1.51
INTERPLAY	6s	90	3mm	11.06	90.93	1.36
INTERPLAY	8s	0	3mm	10.35	96.06	1.22
INTERPLAY	8s	90	3mm	11.36	93.25	1.58
INTERPLAY	6s	0	5mm	11.44	89.50	1.14
INTERPLAY	6s	90	5mm	10.98	96.83	3.83
INTERPLAY	8s	0	5mm	10.54	92.41	0.63
INTERPLAY	8s	90	5mm	10.86	94.36	2.73
INTERPLAY	6s	0	7mm	9.75	97.09	1.58
INTERPLAY	6s	90	7mm	8.92	96.31	0.55
INTERPLAY	8s	0	7mm	10.81	98.45	4.50
INTERPLAY	8s	90	7mm	11.06	94.25	2.43
GATING	6s	0	0mm	7.09	99.04	0.22
GATING	6s	90	0mm	7.45	98.93	0.18
GATING	8s	0	0mm	7.53	98.16	0.44
GATING	8s	90	0mm	8.06	96.98	0.22
GATING	6s	0	3mm	6.43	99.93	0.00
GATING	6s	90	3mm	6.43	100.00	0.04
GATING	8s	0	3mm	6.27	99.93	0.15
GATING	8s	90	3mm	6.27	99.85	0.15
GATING	6s	0	5mm	6.44	99.89	0.04
GATING	6s	90	5mm	6.35	99.85	0.04
GATING	8s	0	5mm	5.82	99.71	0.00
GATING	8s	90	5mm	6.40	98.71	0.07
GATING	6s	0	7mm	5.22	99.96	0.04
GATING	6s	90	7mm	5.16	100.00	0.00
GATING	8s	0	7mm	5.02	100.00	0.00
GATING	8s	90	7mm	5.00	100.00	0.00

Table 1.10: Patient 3, RPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	1.89	100.00	0.00
STATIC	-	-	3mm	1.82	100.00	0.00
STATIC	-	-	5mm	1.81	100.00	0.00
STATIC	-	-	7mm	1.86	100.00	0.00
INTERPLAY	6s	0	0mm	12.34	88.95	1.01
INTERPLAY	6s	90	0mm	12.23	91.57	3.84
INTERPLAY	8s	0	0mm	12.39	91.63	3.69
INTERPLAY	8s	90	0mm	11.66	93.24	3.05
INTERPLAY	6s	0	3mm	9.29	95.81	0.56
INTERPLAY	6s	90	3mm	9.46	97.11	1.26
INTERPLAY	8s	0	3mm	12.20	92.64	3.05
INTERPLAY	8s	90	3mm	12.80	92.04	5.07
INTERPLAY	6s	0	5mm	8.79	98.39	1.42
INTERPLAY	6s	90	5mm	9.26	97.42	0.91
INTERPLAY	8s	0	5mm	10.30	97.01	1.88
INTERPLAY	8s	90	5mm	9.88	96.19	1.15
INTERPLAY	6s	0	7mm	9.31	97.32	1.09
INTERPLAY	6s	90	7mm	8.63	98.78	0.49
INTERPLAY	8s	0	7mm	10.44	94.89	1.79
INTERPLAY	8s	90	7mm	9.97	95.98	0.72
GATING	6s	0	0mm	5.00	99.86	0.00
GATING	6s	90	0mm	5.02	99.86	0.00
GATING	8s	0	0mm	5.31	99.86	0.00
GATING	8s	90	0mm	5.57	99.77	0.06
GATING	6s	0	3mm	4.49	100.00	0.00
GATING	6s	90	3mm	4.58	100.00	0.00
GATING	8s	0	3mm	4.49	100.00	0.06
GATING	8s	90	3mm	4.88	100.00	0.02
GATING	6s	0	5mm	4.94	100.00	0.00
GATING	6s	90	5mm	4.89	100.00	0.00
GATING	8s	0	5mm	4.45	100.00	0.00
GATING	8s	90	5mm	4.29	100.00	0.00
GATING	6s	0	7mm	4.08	100.00	0.00
GATING	6s	90	7mm	3.89	100.00	0.00
GATING	8s	0	7mm	3.85	99.98	0.00
GATING	8s	90	7mm	3.84	100.00	0.00

Table 1.11: Patient 4, LPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	1.90	100.00	0.00
STATIC	-	-	3mm	1.83	100.00	0.00
STATIC	-	-	5mm	1.87	100.00	0.00
STATIC	-	-	7mm	1.82	100.00	0.00
INTERPLAY	6s	0	0mm	11.02	93.01	1.20
INTERPLAY	6s	90	0mm	10.34	93.08	1.13
INTERPLAY	8s	0	0mm	16.87	84.43	7.32
INTERPLAY	8s	90	0mm	14.22	85.89	4.92
INTERPLAY	6s	0	3mm	6.43	99.40	0.00
INTERPLAY	6s	90	3mm	7.46	98.74	0.07
INTERPLAY	8s	0	3mm	11.73	90.69	2.53
INTERPLAY	8s	90	3mm	12.31	85.43	0.86
INTERPLAY	6s	0	5mm	6.66	98.20	0.00
INTERPLAY	6s	90	5mm	7.47	98.94	0.00
INTERPLAY	8s	0	5mm	9.12	96.67	0.73
INTERPLAY	8s	90	5mm	9.91	94.48	0.47
INTERPLAY	6s	0	7mm	6.21	97.94	0.00
INTERPLAY	6s	90	7mm	7.09	98.60	0.00
INTERPLAY	8s	0	7mm	7.18	98.14	0.00
INTERPLAY	8s	90	7mm	6.74	99.53	0.60
GATING	6s	0	0mm	3.89	99.93	0.00
GATING	6s	90	0mm	3.81	99.93	0.00
GATING	8s	0	0mm	3.94	99.93	0.00
GATING	8s	90	0mm	4.48	99.87	0.00
GATING	6s	0	3mm	2.87	100.00	0.00
GATING	6s	90	3mm	2.88	100.00	0.00
GATING	8s	0	3mm	3.20	100.00	0.00
GATING	8s	90	3mm	3.10	100.00	0.00
GATING	6s	0	5mm	2.90	100.00	0.00
GATING	6s	90	5mm	3.03	100.00	0.00
GATING	8s	0	5mm	2.94	100.00	0.00
GATING	8s	90	5mm	3.13	100.00	0.00
GATING	6s	0	7mm	2.99	100.00	0.00
GATING	6s	90	7mm	3.01	100.00	0.00
GATING	8s	0	7mm	2.88	100.00	0.00
GATING	8s	90	7mm	2.83	100.00	0.00

Table 1.12: Patient 4, RPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	1.83	100.00	0.00
STATIC	-	-	3mm	1.80	100.00	0.00
STATIC	-	-	5mm	1.80	100.00	0.00
STATIC	-	-	7mm	1.80	100.00	0.00
INTERPLAY	6s	0	0mm	12.60	89.91	1.94
INTERPLAY	6s	90	0mm	11.01	90.89	1.82
INTERPLAY	8s	0	0mm	13.99	87.18	5.29
INTERPLAY	8s	90	0mm	13.89	86.21	3.71
INTERPLAY	6s	0	3mm	9.72	93.13	0.30
INTERPLAY	6s	90	3mm	9.21	96.60	0.61
INTERPLAY	8s	0	3mm	10.68	91.92	1.46
INTERPLAY	8s	90	3mm	11.23	91.07	1.52
INTERPLAY	6s	0	5mm	9.77	95.57	0.18
INTERPLAY	6s	90	5mm	8.60	98.12	0.24
INTERPLAY	8s	0	5mm	9.75	94.47	0.43
INTERPLAY	8s	90	5mm	9.55	97.21	1.28
INTERPLAY	6s	0	7mm	6.84	96.17	0.00
INTERPLAY	6s	90	7mm	6.25	99.70	0.00
INTERPLAY	8s	0	7mm	8.04	98.66	0.00
INTERPLAY	8s	90	7mm	8.81	93.92	0.00
GATING	6s	0	0mm	4.81	100.00	0.00
GATING	6s	90	0mm	4.86	100.00	0.00
GATING	8s	0	0mm	5.46	100.00	0.06
GATING	8s	90	0mm	5.21	99.94	0.12
GATING	6s	0	3mm	4.04	100.00	0.00
GATING	6s	90	3mm	4.03	100.00	0.00
GATING	8s	0	3mm	4.10	100.00	0.00
GATING	8s	90	3mm	4.26	100.00	0.00
GATING	6s	0	5mm	3.61	100.00	0.00
GATING	6s	90	5mm	3.64	100.00	0.00
GATING	8s	0	5mm	3.59	100.00	0.00
GATING	8s	90	5mm	3.62	100.00	0.00
GATING	6s	0	7mm	2.79	100.00	0.00
GATING	6s	90	7mm	2.81	100.00	0.00
GATING	8s	0	7mm	3.29	100.00	0.00
GATING	8s	90	7mm	3.24	100.00	0.00

Table 1.13: Patient 5, LPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	1.94	100.00	0.00
STATIC	-	-	3mm	1.84	100.00	0.00
STATIC	-	-	5mm	1.83	100.00	0.00
STATIC	-	-	7mm	1.82	100.00	0.00
INTERPLAY	6s	0	0mm	18.21	89.36	18.18
INTERPLAY	6s	90	0mm	14.34	88.25	5.10
INTERPLAY	8s	0	0mm	16.67	81.26	7.87
INTERPLAY	8s	90	0mm	14.40	92.13	8.98
INTERPLAY	6s	0	3mm	14.58	89.14	6.32
INTERPLAY	6s	90	3mm	12.31	88.58	1.66
INTERPLAY	8s	0	3mm	14.69	85.92	6.98
INTERPLAY	8s	90	3mm	14.49	90.02	6.76
INTERPLAY	6s	0	5mm	10.64	83.92	0.11
INTERPLAY	6s	90	5mm	13.25	95.57	7.76
INTERPLAY	8s	0	5mm	14.70	92.35	14.74
INTERPLAY	8s	90	5mm	11.10	87.92	0.44
INTERPLAY	6s	0	7mm	8.34	99.89	1.44
INTERPLAY	6s	90	7mm	7.34	96.01	0.00
INTERPLAY	8s	0	7mm	10.66	96.34	1.77
INTERPLAY	8s	90	7mm	10.14	95.57	0.22
GATING	6s	0	0mm	7.22	99.45	0.67
GATING	6s	90	0mm	7.21	99.45	0.67
GATING	8s	0	0mm	8.88	95.23	0.33
GATING	8s	90	0mm	9.18	95.23	0.11
GATING	6s	0	3mm	6.10	98.78	0.00
GATING	6s	90	3mm	6.16	98.56	0.11
GATING	8s	0	3mm	7.27	99.78	0.00
GATING	8s	90	3mm	7.71	99.45	0.00
GATING	6s	0	5mm	6.81	98.45	0.00
GATING	6s	90	5mm	6.76	98.45	0.00
GATING	8s	0	5mm	7.44	97.34	0.00
GATING	8s	90	5mm	7.25	97.56	0.00
GATING	6s	0	7mm	5.28	98.89	0.00
GATING	6s	90	7mm	5.43	99.00	0.00
GATING	8s	0	7mm	5.60	100.00	0.00
GATING	8s	90	7mm	5.36	100.00	0.00

Table 1.14: Patient 5, RPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	1.85	100.00	0.00
STATIC	-	-	3mm	1.85	100.00	0.00
STATIC	-	-	5mm	1.81	100.00	0.00
STATIC	-	-	7mm	1.81	100.00	0.00
INTERPLAY	6s	0	0mm	12.27	95.36	6.05
INTERPLAY	6s	90	0mm	11.59	93.63	2.38
INTERPLAY	8s	0	0mm	16.30	86.88	8.91
INTERPLAY	8s	90	0mm	12.29	94.87	5.35
INTERPLAY	6s	0	3mm	11.61	95.52	4.16
INTERPLAY	6s	90	3mm	9.22	94.98	0.92
INTERPLAY	8s	0	3mm	12.87	87.53	2.86
INTERPLAY	8s	90	3mm	12.27	97.68	7.02
INTERPLAY	6s	0	5mm	11.58	92.98	1.46
INTERPLAY	6s	90	5mm	11.04	95.25	2.70
INTERPLAY	8s	0	5mm	12.42	86.77	1.84
INTERPLAY	8s	90	5mm	12.55	86.45	2.05
INTERPLAY	6s	0	7mm	9.05	99.08	0.59
INTERPLAY	6s	90	7mm	8.15	98.92	0.11
INTERPLAY	8s	0	7mm	8.60	98.11	0.65
INTERPLAY	8s	90	7mm	8.96	98.87	1.46
GATING	6s	0	0mm	5.79	99.89	0.00
GATING	6s	90	0mm	5.78	99.89	0.00
GATING	8s	0	0mm	5.44	99.62	0.00
GATING	8s	90	0mm	5.38	99.68	0.00
GATING	6s	0	3mm	5.19	100.00	0.00
GATING	6s	90	3mm	5.10	100.00	0.00
GATING	8s	0	3mm	5.99	100.00	0.00
GATING	8s	90	3mm	5.67	100.00	0.00
GATING	6s	0	5mm	4.54	99.89	0.00
GATING	6s	90	5mm	4.57	99.95	0.00
GATING	8s	0	5mm	4.62	100.00	0.00
GATING	8s	90	5mm	4.92	100.00	0.00
GATING	6s	0	7mm	3.86	100.00	0.00
GATING	6s	90	7mm	3.83	100.00	0.00
GATING	8s	0	7mm	4.27	100.00	0.00
GATING	8s	90	7mm	4.68	100.00	0.00

Table 1.15: Patient 6, LPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	1.86	100.00	0.00
STATIC	-	-	3mm	1.84	100.00	0.00
STATIC	-	-	5mm	1.81	100.00	0.00
STATIC	-	-	7mm	1.83	100.00	0.00
INTERPLAY	6s	0	0mm	12.07	91.36	4.04
INTERPLAY	6s	90	0mm	12.94	86.83	1.13
INTERPLAY	8s	0	0mm	17.12	75.14	5.17
INTERPLAY	8s	90	0mm	16.66	81.02	4.32
INTERPLAY	6s	0	3mm	11.39	95.25	3.54
INTERPLAY	6s	90	3mm	8.61	96.60	0.35
INTERPLAY	8s	0	3mm	10.19	93.41	0.42
INTERPLAY	8s	90	3mm	11.22	94.41	2.62
INTERPLAY	6s	0	5mm	8.22	97.80	0.57
INTERPLAY	6s	90	5mm	8.17	96.32	0.00
INTERPLAY	8s	0	5mm	11.32	90.37	1.20
INTERPLAY	8s	90	5mm	10.66	92.42	1.20
INTERPLAY	6s	0	7mm	7.62	97.52	0.00
INTERPLAY	6s	90	7mm	8.20	96.88	0.14
INTERPLAY	8s	0	7mm	9.18	92.78	0.71
INTERPLAY	8s	90	7mm	8.25	94.83	0.00
GATING	6s	0	0mm	7.75	96.32	0.00
GATING	6s	90	0mm	7.83	95.96	0.00
GATING	8s	0	0mm	7.48	97.95	0.00
GATING	8s	90	0mm	7.49	98.37	0.00
GATING	6s	0	3mm	4.92	100.00	0.00
GATING	6s	90	3mm	4.92	100.00	0.00
GATING	8s	0	3mm	5.04	100.00	0.00
GATING	8s	90	3mm	4.63	100.00	0.00
GATING	6s	0	5mm	4.21	100.00	0.00
GATING	6s	90	5mm	4.17	100.00	0.00
GATING	8s	0	5mm	4.34	100.00	0.00
GATING	8s	90	5mm	4.21	100.00	0.00
GATING	6s	0	7mm	4.13	100.00	0.00
GATING	6s	90	7mm	4.12	100.00	0.00
GATING	8s	0	7mm	4.45	100.00	0.00
GATING	8s	90	7mm	4.26	100.00	0.00

Table 1.16: Patient 6, RPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	1.84	100.00	0.00
STATIC	-	-	3mm	1.81	100.00	0.00
STATIC	-	-	5mm	1.81	100.00	0.00
STATIC	-	-	7mm	1.82	100.00	0.00
INTERPLAY	6s	0	0mm	10.31	96.14	3.00
INTERPLAY	6s	90	0mm	10.75	91.82	0.60
INTERPLAY	8s	0	0mm	10.86	95.68	2.93
INTERPLAY	8s	90	0mm	8.92	98.27	1.31
INTERPLAY	6s	0	3mm	10.26	98.05	3.75
INTERPLAY	6s	90	3mm	7.78	98.05	0.08
INTERPLAY	8s	0	3mm	9.51	97.07	1.73
INTERPLAY	8s	90	3mm	8.26	98.80	0.64
INTERPLAY	6s	0	5mm	7.57	99.10	1.05
INTERPLAY	6s	90	5mm	7.80	99.44	0.83
INTERPLAY	8s	0	5mm	8.46	95.68	0.26
INTERPLAY	8s	90	5mm	7.17	98.16	0.15
INTERPLAY	6s	0	7mm	6.83	99.77	0.00
INTERPLAY	6s	90	7mm	8.54	99.70	2.03
INTERPLAY	8s	0	7mm	7.30	97.82	0.08
INTERPLAY	8s	90	7mm	7.45	97.07	0.08
GATING	6s	0	0mm	6.72	98.20	0.08
GATING	6s	90	0mm	6.85	98.20	0.00
GATING	8s	0	0mm	6.47	99.59	0.04
GATING	8s	90	0mm	6.06	99.74	0.26
GATING	6s	0	3mm	5.09	100.00	0.00
GATING	6s	90	3mm	5.23	99.96	0.00
GATING	8s	0	3mm	5.84	98.69	0.00
GATING	8s	90	3mm	5.04	99.96	0.08
GATING	6s	0	5mm	4.57	100.00	0.00
GATING	6s	90	5mm	4.60	100.00	0.00
GATING	8s	0	5mm	4.91	100.00	0.00
GATING	8s	90	5mm	4.87	100.00	0.04
GATING	6s	0	7mm	4.79	99.14	0.00
GATING	6s	90	7mm	4.89	99.14	0.00
GATING	8s	0	7mm	4.03	100.00	0.00
GATING	8s	90	7mm	4.10	99.96	0.00

Table 1.17: Patient 7, LPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	1.94	100.00	0.00
STATIC	-	-	3mm	1.91	100.00	0.00
STATIC	-	-	5mm	1.82	100.00	0.00
STATIC	-	-	7mm	1.83	100.00	0.00
INTERPLAY	6s	0	0mm	9.82	96.78	2.00
INTERPLAY	6s	90	0mm	13.32	89.78	4.16
INTERPLAY	8s	0	0mm	9.07	98.61	1.78
INTERPLAY	8s	90	0mm	9.51	97.89	2.44
INTERPLAY	6s	0	3mm	6.04	99.94	0.06
INTERPLAY	6s	90	3mm	7.69	95.78	0.00
INTERPLAY	8s	0	3mm	10.55	94.45	2.61
INTERPLAY	8s	90	3mm	8.83	94.45	0.50
INTERPLAY	6s	0	5mm	7.87	98.45	0.00
INTERPLAY	6s	90	5mm	5.85	99.50	0.00
INTERPLAY	8s	0	5mm	8.96	96.67	0.78
INTERPLAY	8s	90	5mm	8.23	96.72	0.11
INTERPLAY	6s	0	7mm	5.48	99.83	0.00
INTERPLAY	6s	90	7mm	6.16	99.44	0.00
INTERPLAY	8s	0	7mm	6.63	98.94	0.00
INTERPLAY	8s	90	7mm	7.18	99.78	0.06
GATING	6s	0	0mm	6.55	99.28	0.00
GATING	6s	90	0mm	6.60	99.11	0.00
GATING	8s	0	0mm	5.70	99.78	0.06
GATING	8s	90	0mm	5.55	99.72	0.00
GATING	6s	0	3mm	3.46	100.00	0.00
GATING	6s	90	3mm	3.51	100.00	0.00
GATING	8s	0	3mm	3.66	100.00	0.00
GATING	8s	90	3mm	3.71	100.00	0.00
GATING	6s	0	5mm	3.66	100.00	0.00
GATING	6s	90	5mm	3.63	100.00	0.00
GATING	8s	0	5mm	3.65	100.00	0.00
GATING	8s	90	5mm	3.56	100.00	0.00
GATING	6s	0	7mm	3.70	99.94	0.00
GATING	6s	90	7mm	3.69	99.94	0.00
GATING	8s	0	7mm	3.40	99.94	0.00
GATING	8s	90	7mm	3.41	100.00	0.00

Table 1.18: Patient 7, RPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	1.98	100.00	0.00
STATIC	-	-	3mm	1.80	100.00	0.00
STATIC	-	-	5mm	1.81	100.00	0.00
STATIC	-	-	7mm	1.80	100.00	0.00
INTERPLAY	6s	0	0mm	9.07	96.63	0.81
INTERPLAY	6s	90	0mm	8.12	98.80	0.46
INTERPLAY	8s	0	0mm	9.16	97.10	0.39
INTERPLAY	8s	90	0mm	9.57	95.28	0.31
INTERPLAY	6s	0	3mm	6.02	100.00	0.00
INTERPLAY	6s	90	3mm	6.76	99.23	0.00
INTERPLAY	8s	0	3mm	7.28	99.69	0.39
INTERPLAY	8s	90	3mm	7.52	99.23	0.04
INTERPLAY	6s	0	5mm	6.53	99.26	0.00
INTERPLAY	6s	90	5mm	5.62	99.77	0.00
INTERPLAY	8s	0	5mm	7.31	98.68	0.00
INTERPLAY	8s	90	5mm	6.23	99.81	0.00
INTERPLAY	6s	0	7mm	5.87	99.73	0.00
INTERPLAY	6s	90	7mm	6.25	99.81	0.00
INTERPLAY	8s	0	7mm	6.06	99.73	0.00
INTERPLAY	8s	90	7mm	5.99	99.34	0.04
GATING	6s	0	0mm	7.19	98.95	0.58
GATING	6s	90	0mm	7.05	98.99	0.50
GATING	8s	0	0mm	6.05	100.00	0.08
GATING	8s	90	0mm	6.14	100.00	0.35
GATING	6s	0	3mm	5.23	100.00	0.00
GATING	6s	90	3mm	5.23	100.00	0.00
GATING	8s	0	3mm	5.29	99.77	0.00
GATING	8s	90	3mm	5.25	99.92	0.00
GATING	6s	0	5mm	5.34	99.96	0.00
GATING	6s	90	5mm	5.29	100.00	0.00
GATING	8s	0	5mm	3.92	99.92	0.00
GATING	8s	90	5mm	4.03	99.85	0.00
GATING	6s	0	7mm	4.06	100.00	0.00
GATING	6s	90	7mm	4.06	100.00	0.00
GATING	8s	0	7mm	3.76	100.00	0.00
GATING	8s	90	7mm	4.27	100.00	0.00

Table 1.19: Patient 8, LPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	1.87	100.00	0.00
STATIC	-	-	3mm	1.83	100.00	0.00
STATIC	-	-	5mm	1.82	100.00	0.00
STATIC	-	-	7mm	1.87	100.00	0.00
INTERPLAY	6s	0	0mm	14.40	90.64	6.93
INTERPLAY	6s	90	0mm	13.52	87.62	2.64
INTERPLAY	8s	0	0mm	12.77	90.54	4.64
INTERPLAY	8s	90	0mm	13.36	92.68	6.16
INTERPLAY	6s	0	3mm	11.81	89.48	0.70
INTERPLAY	6s	90	3mm	9.36	96.55	1.23
INTERPLAY	8s	0	3mm	11.30	92.16	1.48
INTERPLAY	8s	90	3mm	11.67	90.78	1.93
INTERPLAY	6s	0	5mm	9.04	97.96	0.46
INTERPLAY	6s	90	5mm	9.32	94.58	0.25
INTERPLAY	8s	0	5mm	10.09	95.81	2.00
INTERPLAY	8s	90	5mm	10.69	94.69	1.93
INTERPLAY	6s	0	7mm	8.53	98.49	1.06
INTERPLAY	6s	90	7mm	9.93	98.03	1.51
INTERPLAY	8s	0	7mm	8.46	97.50	0.56
INTERPLAY	8s	90	7mm	9.27	96.62	0.49
GATING	6s	0	0mm	8.30	94.55	0.00
GATING	6s	90	0mm	8.43	94.44	0.00
GATING	8s	0	0mm	7.57	95.29	0.04
GATING	8s	90	0mm	7.77	95.15	0.07
GATING	6s	0	3mm	4.51	99.93	0.00
GATING	6s	90	3mm	4.51	99.93	0.00
GATING	8s	0	3mm	4.72	99.96	0.04
GATING	8s	90	3mm	4.86	100.00	0.04
GATING	6s	0	5mm	4.70	100.00	0.00
GATING	6s	90	5mm	4.66	100.00	0.00
GATING	8s	0	5mm	4.34	100.00	0.00
GATING	8s	90	5mm	4.36	100.00	0.00
GATING	6s	0	7mm	3.86	100.00	0.00
GATING	6s	90	7mm	3.86	100.00	0.00
GATING	8s	0	7mm	3.80	100.00	0.00
GATING	8s	90	7mm	3.79	100.00	0.00

Table 1.20: Patient 8, RPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	1.85	100.00	0.00
STATIC	-	-	3mm	1.82	100.00	0.00
STATIC	-	-	5mm	1.81	100.00	0.00
STATIC	-	-	7mm	1.81	100.00	0.00
INTERPLAY	6s	0	0mm	16.96	86.51	11.76
INTERPLAY	6s	90	0mm	14.01	89.57	5.64
INTERPLAY	8s	0	0mm	12.52	95.65	7.61
INTERPLAY	8s	90	0mm	12.15	92.63	3.61
INTERPLAY	6s	0	3mm	11.49	87.99	2.47
INTERPLAY	6s	90	3mm	15.13	81.07	6.72
INTERPLAY	8s	0	3mm	13.77	86.16	3.86
INTERPLAY	8s	90	3mm	10.66	90.36	1.48
INTERPLAY	6s	0	5mm	12.35	89.72	1.43
INTERPLAY	6s	90	5mm	12.44	96.69	6.87
INTERPLAY	8s	0	5mm	8.72	96.19	0.30
INTERPLAY	8s	90	5mm	9.45	98.52	1.68
INTERPLAY	6s	0	7mm	12.64	96.89	7.12
INTERPLAY	6s	90	7mm	10.21	94.02	0.84
INTERPLAY	8s	0	7mm	9.53	99.90	3.71
INTERPLAY	8s	90	7mm	10.06	98.37	2.97
GATING	6s	0	0mm	5.64	99.06	0.00
GATING	6s	90	0mm	5.63	99.11	0.00
GATING	8s	0	0mm	5.67	99.21	0.15
GATING	8s	90	0mm	6.06	99.11	0.20
GATING	6s	0	3mm	4.29	100.00	0.00
GATING	6s	90	3mm	4.29	100.00	0.00
GATING	8s	0	3mm	4.83	100.00	0.00
GATING	8s	90	3mm	4.87	100.00	0.00
GATING	6s	0	5mm	4.85	99.85	0.00
GATING	6s	90	5mm	4.79	99.80	0.00
GATING	8s	0	5mm	5.23	99.85	0.00
GATING	8s	90	5mm	5.09	100.00	0.00
GATING	6s	0	7mm	4.62	99.95	0.00
GATING	6s	90	7mm	4.38	100.00	0.00
GATING	8s	0	7mm	4.72	99.90	0.00
GATING	8s	90	7mm	4.60	99.95	0.00

Table 1.21: Patient 9, LPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	1.83	100.00	0.00
STATIC	-	-	3mm	1.86	100.00	0.00
STATIC	-	-	5mm	1.82	100.00	0.00
STATIC	-	-	7mm	1.81	100.00	0.00
INTERPLAY	6s	0	0mm	22.96	73.82	4.62
INTERPLAY	6s	90	0mm	15.96	83.98	5.95
INTERPLAY	8s	0	0mm	17.89	77.70	9.08
INTERPLAY	8s	90	0mm	24.83	84.15	19.08
INTERPLAY	6s	0	3mm	19.57	72.91	5.70
INTERPLAY	6s	90	3mm	20.93	84.31	13.46
INTERPLAY	8s	0	3mm	12.89	89.18	2.06
INTERPLAY	8s	90	3mm	12.54	90.01	0.58
INTERPLAY	6s	0	5mm	16.02	83.15	4.87
INTERPLAY	6s	90	5mm	13.18	90.50	3.72
INTERPLAY	8s	0	5mm	13.85	90.17	7.10
INTERPLAY	8s	90	5mm	13.01	83.98	0.91
INTERPLAY	6s	0	7mm	14.77	84.48	3.96
INTERPLAY	6s	90	7mm	16.28	87.70	3.39
INTERPLAY	8s	0	7mm	14.30	82.74	3.55
INTERPLAY	8s	90	7mm	15.55	91.08	15.28
GATING	6s	0	0mm	8.03	94.14	0.08
GATING	6s	90	0mm	7.77	94.55	0.08
GATING	8s	0	0mm	7.79	95.21	0.00
GATING	8s	90	0mm	6.71	96.94	0.00
GATING	6s	0	3mm	4.90	99.92	0.00
GATING	6s	90	3mm	5.01	100.00	0.00
GATING	8s	0	3mm	4.72	99.83	0.00
GATING	8s	90	3mm	4.12	100.00	0.00
GATING	6s	0	5mm	4.70	100.00	0.00
GATING	6s	90	5mm	4.42	100.00	0.00
GATING	8s	0	5mm	3.92	100.00	0.00
GATING	8s	90	5mm	4.42	100.00	0.00
GATING	6s	0	7mm	3.96	100.00	0.00
GATING	6s	90	7mm	4.18	99.92	0.00
GATING	8s	0	7mm	3.47	100.00	0.00
GATING	8s	90	7mm	3.59	100.00	0.00

Table 1.22: Patient 9, RPV

Case	motion period	motion starting phase	Margin	D5-D95	V95	V107
STATIC	-	-	0mm	1.81	100.00	0.00
STATIC	-	-	3mm	1.81	100.00	0.00
STATIC	-	-	5mm	1.82	100.00	0.00
STATIC	-	-	7mm	1.80	100.00	0.00
INTERPLAY	6s	0	0mm	21.06	81.96	15.73
INTERPLAY	6s	90	0mm	16.08	95.00	16.37
INTERPLAY	8s	0	0mm	14.47	82.98	4.44
INTERPLAY	8s	90	0mm	13.16	92.88	5.83
INTERPLAY	6s	0	3mm	12.22	90.38	1.85
INTERPLAY	6s	90	3mm	12.82	92.41	3.52
INTERPLAY	8s	0	3mm	9.28	97.04	1.20
INTERPLAY	8s	90	3mm	8.07	99.17	0.09
INTERPLAY	6s	0	5mm	10.72	95.93	2.31
INTERPLAY	6s	90	5mm	9.86	99.44	3.89
INTERPLAY	8s	0	5mm	9.57	96.85	1.02
INTERPLAY	8s	90	5mm	11.19	93.62	1.30
INTERPLAY	6s	0	7mm	8.96	99.54	1.02
INTERPLAY	6s	90	7mm	9.63	97.87	1.20
INTERPLAY	8s	0	7mm	10.82	96.67	3.15
INTERPLAY	8s	90	7mm	13.80	95.65	11.38
GATING	6s	0	0mm	6.18	98.98	0.00
GATING	6s	90	0mm	6.05	99.07	0.00
GATING	8s	0	0mm	5.35	98.98	0.00
GATING	8s	90	0mm	5.19	99.17	0.00
GATING	6s	0	3mm	4.14	100.00	0.00
GATING	6s	90	3mm	4.42	99.91	0.00
GATING	8s	0	3mm	5.07	99.91	0.00
GATING	8s	90	3mm	4.82	99.82	0.00
GATING	6s	0	5mm	3.43	100.00	0.00
GATING	6s	90	5mm	3.38	100.00	0.00
GATING	8s	0	5mm	3.87	100.00	0.00
GATING	8s	90	5mm	3.85	100.00	0.00
GATING	6s	0	7mm	3.18	100.00	0.00
GATING	6s	90	7mm	3.33	100.00	0.00
GATING	8s	0	7mm	3.59	100.00	0.00
GATING	8s	90	7mm	3.48	100.00	0.00

Table 1.23: Patient 2, LPV

Case	Rescan no.	motion period	motion starting phase	Margin	D5-D95	V95	V107
RESCANNING	5	6s	0	0mm	6.08	98.89	0.52
RESCANNING	10	6s	0	0mm	5.69	98.63	0.13
RESCANNING	15	6s	0	0mm	5.56	98.76	0.13
RESCANNING	20	6s	0	0mm	5.63	98.63	0.07
RESCANNING	5	6s	90	0mm	6.08	98.89	0.52
RESCANNING	10	6s	90	0mm	5.69	98.63	0.13
RESCANNING	15	6s	90	0mm	5.56	98.76	0.13
RESCANNING	20	6s	90	0mm	5.63	98.63	0.07
RESCANNING	5	8s	0	0mm	5.97	98.30	0.13
RESCANNING	10	8s	0	0mm	5.69	98.30	0.26
RESCANNING	15	8s	0	0mm	5.91	97.97	0.26
RESCANNING	20	8s	0	0mm	6.14	98.82	0.20
RESCANNING	5	8s	90	0mm	5.78	98.17	0.13
RESCANNING	10	8s	90	0mm	5.65	98.30	0.26
RESCANNING	15	8s	90	0mm	5.82	98.50	0.13
RESCANNING	20	8s	90	0mm	5.95	98.95	0.13
RESCANNING	5	6s	0	3mm	4.72	100.00	0.00
RESCANNING	10	6s	0	3mm	3.64	100.00	0.00
RESCANNING	15	6s	0	3mm	3.78	99.93	0.00
RESCANNING	20	6s	0	3mm	3.74	99.80	0.00
RESCANNING	5	6s	90	3mm	4.69	100.00	0.00
RESCANNING	10	6s	90	3mm	3.75	99.87	0.00
RESCANNING	15	6s	90	3mm	3.95	100.00	0.00
RESCANNING	20	6s	90	3mm	3.71	99.87	0.00
RESCANNING	5	8s	0	3mm	4.54	99.80	0.00
RESCANNING	10	8s	0	3mm	3.89	100.00	0.00
RESCANNING	15	8s	0	3mm	3.80	100.00	0.00
RESCANNING	20	8s	0	3mm	3.88	100.00	0.00
RESCANNING	5	8s	90	3mm	4.71	99.74	0.00
RESCANNING	10	8s	90	3mm	3.85	100.00	0.00
RESCANNING	15	8s	90	3mm	3.85	100.00	0.00
RESCANNING	20	8s	90	3mm	4.24	100.00	0.00
RESCANNING	5	6s	0	5mm	3.70	100.00	0.00
RESCANNING	10	6s	0	5mm	3.83	100.00	0.00
RESCANNING	15	6s	0	5mm	3.74	100.00	0.00
RESCANNING	20	6s	0	5mm	3.63	100.00	0.00
RESCANNING	5	6s	90	5mm	3.70	100.00	0.00
RESCANNING	10	6s	90	5mm	3.83	100.00	0.00
RESCANNING	15	6s	90	5mm	3.74	100.00	0.00
RESCANNING	20	6s	90	5mm	3.63	100.00	0.00
RESCANNING	5	8s	0	5mm	3.81	100.00	0.00
RESCANNING	10	8s	0	5mm	3.64	100.00	0.00
RESCANNING	15	8s	0	5mm	3.58	100.00	0.00
RESCANNING	20	8s	0	5mm	3.70	100.00	0.00
RESCANNING	5	8s	90	5mm	4.02	99.93	0.00
RESCANNING	10	8s	90	5mm	3.66	100.00	0.00
RESCANNING	15	8s	90	5mm	3.54	100.00	0.00
RESCANNING	20	8s	90	5mm	3.66	100.00	0.00
RESCANNING	5	6s	0	7mm	3.63	100.00	0.00
RESCANNING	10	6s	0	7mm	3.46	100.00	0.00
RESCANNING	15	6s	0	7mm	3.43	100.00	0.00
RESCANNING	20	6s	0	7mm	3.43	100.00	0.00
RESCANNING	5	6s	90	7mm	3.63	100.00	0.00
RESCANNING	10	6s	90	7mm	3.48	100.00	0.00
RESCANNING	15	6s	90	7mm	3.44	100.00	0.00
RESCANNING	20	6s	90	7mm	3.46	100.00	0.00
RESCANNING	5	8s	0	7mm	3.56	100.00	0.00
RESCANNING	10	8s	0	7mm	3.46	100.00	0.00
RESCANNING	15	8s	0	7mm	3.70	100.00	0.00
RESCANNING	20	8s	0	7mm	3.55	100.00	0.00
RESCANNING	5	8s	90	7mm	3.62	100.00	0.00
RESCANNING	10	8s	90	7mm	3.46	100.00	0.00
RESCANNING	15	8s	90	7mm	3.67	100.00	0.00
RESCANNING	20	8s	90	7mm	3.52	100.00	0.00

Table 1.24: Patient 2, RPV

Case	Rescan no.	motion period	motion starting phase	Margin	D5-D95	V95	V107
RESCANNING	5	6s	0	0mm	6.68	96.29	0.00
RESCANNING	10	6s	0	0mm	6.29	95.89	0.05
RESCANNING	15	6s	0	0mm	6.01	96.24	0.05
RESCANNING	20	6s	0	0mm	5.62	96.14	0.05
RESCANNING	5	6s	90	0mm	6.70	96.29	0.00
RESCANNING	10	6s	90	0mm	6.33	95.94	0.05
RESCANNING	15	6s	90	0mm	5.84	96.34	0.05
RESCANNING	20	6s	90	0mm	5.62	96.09	0.05
RESCANNING	5	8s	0	0mm	5.92	97.52	0.15
RESCANNING	10	8s	0	0mm	6.37	95.74	0.10
RESCANNING	15	8s	0	0mm	5.75	95.99	0.10
RESCANNING	20	8s	0	0mm	6.13	95.89	0.10
RESCANNING	5	8s	90	0mm	6.11	97.62	0.15
RESCANNING	10	8s	90	0mm	6.54	95.69	0.10
RESCANNING	15	8s	90	0mm	5.85	95.94	0.05
RESCANNING	20	8s	90	0mm	6.10	96.14	0.05
RESCANNING	5	6s	0	3mm	4.84	99.85	0.10
RESCANNING	10	6s	0	3mm	4.02	100.00	0.00
RESCANNING	15	6s	0	3mm	3.85	99.95	0.00
RESCANNING	20	6s	0	3mm	4.09	99.90	0.00
RESCANNING	5	6s	90	3mm	4.78	99.85	0.15
RESCANNING	10	6s	90	3mm	4.11	100.00	0.00
RESCANNING	15	6s	90	3mm	3.82	99.95	0.00
RESCANNING	20	6s	90	3mm	4.01	99.90	0.00
RESCANNING	5	8s	0	3mm	4.41	100.00	0.00
RESCANNING	10	8s	0	3mm	4.11	100.00	0.00
RESCANNING	15	8s	0	3mm	4.30	100.00	0.00
RESCANNING	20	8s	0	3mm	4.05	99.90	0.00
RESCANNING	5	8s	90	3mm	4.47	100.00	0.00
RESCANNING	10	8s	90	3mm	4.38	100.00	0.00
RESCANNING	15	8s	90	3mm	4.26	100.00	0.00
RESCANNING	20	8s	90	3mm	4.10	99.90	0.00
RESCANNING	5	6s	0	5mm	3.82	100.00	0.00
RESCANNING	10	6s	0	5mm	3.77	100.00	0.00
RESCANNING	15	6s	0	5mm	3.63	100.00	0.00
RESCANNING	20	6s	0	5mm	3.57	100.00	0.00
RESCANNING	5	6s	90	5mm	3.82	100.00	0.00
RESCANNING	10	6s	90	5mm	3.77	100.00	0.00
RESCANNING	15	6s	90	5mm	3.64	100.00	0.00
RESCANNING	20	6s	90	5mm	3.57	100.00	0.00
RESCANNING	5	8s	0	5mm	5.16	100.00	0.10
RESCANNING	10	8s	0	5mm	3.71	100.00	0.00
RESCANNING	15	8s	0	5mm	3.61	100.00	0.00
RESCANNING	20	8s	0	5mm	3.87	100.00	0.05
RESCANNING	5	8s	90	5mm	4.87	100.00	0.00
RESCANNING	10	8s	90	5mm	3.77	100.00	0.00
RESCANNING	15	8s	90	5mm	3.60	100.00	0.00
RESCANNING	20	8s	90	5mm	3.83	99.95	0.05
RESCANNING	5	6s	0	7mm	3.75	100.00	0.00
RESCANNING	10	6s	0	7mm	3.48	100.00	0.00
RESCANNING	15	6s	0	7mm	3.26	100.00	0.00
RESCANNING	20	6s	0	7mm	3.48	100.00	0.00
RESCANNING	5	6s	90	7mm	3.75	100.00	0.00
RESCANNING	10	6s	90	7mm	3.48	100.00	0.00
RESCANNING	15	6s	90	7mm	3.32	100.00	0.00
RESCANNING	20	6s	90	7mm	3.50	100.00	0.00
RESCANNING	5	8s	0	7mm	3.94	100.00	0.00
RESCANNING	10	8s	0	7mm	3.39	100.00	0.00
RESCANNING	15	8s	0	7mm	3.43	100.00	0.00
RESCANNING	20	8s	0	7mm	3.46	100.00	0.00
RESCANNING	5	8s	90	7mm	3.78	100.00	0.00
RESCANNING	10	8s	90	7mm	3.39	100.00	0.00
RESCANNING	15	8s	90	7mm	3.43	100.00	0.00
RESCANNING	20	8s	90	7mm	3.46	100.00	0.00

Table 1.25: Patient 9, LPV

Case	Rescan no.	motion period	motion starting phase	Margin	D5-D95	V95	V107
RESCANNING	5	6s	0	0mm	7.70	93.97	0.00
RESCANNING	10	6s	0	0mm	7.91	93.89	0.00
RESCANNING	15	6s	0	0mm	7.64	94.30	0.00
RESCANNING	20	6s	0	0mm	7.98	94.30	0.00
RESCANNING	5	6s	90	0mm	7.86	93.97	0.08
RESCANNING	10	6s	90	0mm	7.80	93.97	0.00
RESCANNING	15	6s	90	0mm	7.66	94.30	0.00
RESCANNING	20	6s	90	0mm	7.93	94.30	0.00
RESCANNING	5	8s	0	0mm	8.73	94.30	0.00
RESCANNING	10	8s	0	0mm	8.39	93.81	0.08
RESCANNING	15	8s	0	0mm	8.75	93.56	0.08
RESCANNING	20	8s	0	0mm	7.96	94.38	0.08
RESCANNING	5	8s	90	0mm	8.57	94.30	0.00
RESCANNING	10	8s	90	0mm	8.70	93.97	0.08
RESCANNING	15	8s	90	0mm	7.46	94.30	0.08
RESCANNING	20	8s	90	0mm	8.03	94.80	0.08
RESCANNING	5	6s	0	3mm	3.86	100.00	0.00
RESCANNING	10	6s	0	3mm	4.06	100.00	0.00
RESCANNING	15	6s	0	3mm	3.75	100.00	0.00
RESCANNING	20	6s	0	3mm	3.69	100.00	0.00
RESCANNING	5	6s	90	3mm	3.83	100.00	0.00
RESCANNING	10	6s	90	3mm	4.10	100.00	0.00
RESCANNING	15	6s	90	3mm	3.74	100.00	0.00
RESCANNING	20	6s	90	3mm	3.70	100.00	0.00
RESCANNING	5	8s	0	3mm	4.26	100.00	0.00
RESCANNING	10	8s	0	3mm	3.92	100.00	0.00
RESCANNING	15	8s	0	3mm	3.93	100.00	0.00
RESCANNING	20	8s	0	3mm	4.08	100.00	0.00
RESCANNING	5	8s	90	3mm	4.26	100.00	0.00
RESCANNING	10	8s	90	3mm	3.96	100.00	0.00
RESCANNING	15	8s	90	3mm	4.02	99.92	0.00
RESCANNING	20	8s	90	3mm	3.89	100.00	0.00
RESCANNING	5	6s	0	5mm	3.73	100.00	0.00
RESCANNING	10	6s	0	5mm	3.61	100.00	0.00
RESCANNING	15	6s	0	5mm	3.50	100.00	0.00
RESCANNING	20	6s	0	5mm	3.65	100.00	0.00
RESCANNING	5	6s	90	5mm	3.73	100.00	0.00
RESCANNING	10	6s	90	5mm	3.63	100.00	0.00
RESCANNING	15	6s	90	5mm	3.52	100.00	0.00
RESCANNING	20	6s	90	5mm	3.67	100.00	0.00
RESCANNING	5	8s	0	5mm	3.73	100.00	0.00
RESCANNING	10	8s	0	5mm	3.63	100.00	0.00
RESCANNING	15	8s	0	5mm	3.59	100.00	0.00
RESCANNING	20	8s	0	5mm	3.58	100.00	0.00
RESCANNING	5	8s	90	5mm	3.73	100.00	0.00
RESCANNING	10	8s	90	5mm	3.68	100.00	0.00
RESCANNING	15	8s	90	5mm	3.61	100.00	0.00
RESCANNING	20	8s	90	5mm	3.58	100.00	0.00
RESCANNING	5	6s	0	7mm	3.89	100.00	0.00
RESCANNING	10	6s	0	7mm	3.45	100.00	0.00
RESCANNING	15	6s	0	7mm	3.19	100.00	0.00
RESCANNING	20	6s	0	7mm	3.22	100.00	0.00
RESCANNING	5	6s	90	7mm	3.83	100.00	0.00
RESCANNING	10	6s	90	7mm	3.45	100.00	0.00
RESCANNING	15	6s	90	7mm	3.16	100.00	0.00
RESCANNING	20	6s	90	7mm	3.23	100.00	0.00
RESCANNING	5	8s	0	7mm	3.56	100.00	0.00
RESCANNING	10	8s	0	7mm	3.81	100.00	0.00
RESCANNING	15	8s	0	7mm	3.48	100.00	0.00
RESCANNING	20	8s	0	7mm	3.34	100.00	0.00
RESCANNING	5	8s	90	7mm	3.77	100.00	0.00
RESCANNING	10	8s	90	7mm	3.61	100.00	0.00
RESCANNING	15	8s	90	7mm	3.41	100.00	0.00
RESCANNING	20	8s	90	7mm	3.42	100.00	0.00

Table 1.26: Patient 9, RPV

Case	Rescan no.	motion period	motion starting phase	Margin	D5-D95	V95	V107
RESCANNING	5	6s	0	0mm	4.72	99.26	0.00
RESCANNING	10	6s	0	0mm	4.48	99.26	0.00
RESCANNING	15	6s	0	0mm	4.22	99.35	0.00
RESCANNING	20	6s	0	0mm	4.07	99.17	0.00
RESCANNING	5	6s	90	0mm	4.81	99.26	0.00
RESCANNING	10	6s	90	0mm	4.47	99.26	0.00
RESCANNING	15	6s	90	0mm	4.31	99.17	0.00
RESCANNING	20	6s	90	0mm	3.98	99.17	0.00
RESCANNING	5	8s	0	0mm	4.94	99.07	0.00
RESCANNING	10	8s	0	0mm	4.68	98.70	0.00
RESCANNING	15	8s	0	0mm	4.50	99.17	0.00
RESCANNING	20	8s	0	0mm	4.50	99.17	0.00
RESCANNING	5	8s	90	0mm	5.11	99.17	0.00
RESCANNING	10	8s	90	0mm	4.63	98.89	0.00
RESCANNING	15	8s	90	0mm	4.27	99.17	0.00
RESCANNING	20	8s	90	0mm	4.58	99.17	0.00
RESCANNING	5	6s	0	3mm	3.93	100.00	0.00
RESCANNING	10	6s	0	3mm	3.64	100.00	0.00
RESCANNING	15	6s	0	3mm	3.47	100.00	0.00
RESCANNING	20	6s	0	3mm	3.60	100.00	0.00
RESCANNING	5	6s	90	3mm	3.94	100.00	0.00
RESCANNING	10	6s	90	3mm	3.64	100.00	0.00
RESCANNING	15	6s	90	3mm	3.49	100.00	0.00
RESCANNING	20	6s	90	3mm	3.57	100.00	0.00
RESCANNING	5	8s	0	3mm	3.94	99.91	0.00
RESCANNING	10	8s	0	3mm	3.75	100.00	0.00
RESCANNING	15	8s	0	3mm	3.84	100.00	0.00
RESCANNING	20	8s	0	3mm	4.03	100.00	0.00
RESCANNING	5	8s	90	3mm	4.05	100.00	0.00
RESCANNING	10	8s	90	3mm	3.69	100.00	0.00
RESCANNING	15	8s	90	3mm	3.63	100.00	0.00
RESCANNING	20	8s	90	3mm	3.59	100.00	0.00
RESCANNING	5	6s	0	5mm	3.60	100.00	0.00
RESCANNING	10	6s	0	5mm	3.11	100.00	0.00
RESCANNING	15	6s	0	5mm	3.06	100.00	0.00
RESCANNING	20	6s	0	5mm	3.20	100.00	0.00
RESCANNING	5	6s	90	5mm	3.61	100.00	0.00
RESCANNING	10	6s	90	5mm	3.16	100.00	0.00
RESCANNING	15	6s	90	5mm	3.22	100.00	0.00
RESCANNING	20	6s	90	5mm	3.19	100.00	0.00
RESCANNING	5	8s	0	5mm	3.75	100.00	0.00
RESCANNING	10	8s	0	5mm	2.97	100.00	0.00
RESCANNING	15	8s	0	5mm	3.69	100.00	0.00
RESCANNING	20	8s	0	5mm	2.93	100.00	0.00
RESCANNING	5	8s	90	5mm	3.78	100.00	0.00
RESCANNING	10	8s	90	5mm	3.48	100.00	0.00
RESCANNING	15	8s	90	5mm	3.71	100.00	0.00
RESCANNING	20	8s	90	5mm	4.15	100.00	0.00
RESCANNING	5	6s	0	7mm	3.74	100.00	0.00
RESCANNING	10	6s	0	7mm	3.58	100.00	0.00
RESCANNING	15	6s	0	7mm	3.43	100.00	0.00
RESCANNING	20	6s	0	7mm	3.42	100.00	0.00
RESCANNING	5	6s	90	7mm	3.74	100.00	0.00
RESCANNING	10	6s	90	7mm	3.58	100.00	0.00
RESCANNING	15	6s	90	7mm	3.45	100.00	0.00
RESCANNING	20	6s	90	7mm	3.43	100.00	0.00
RESCANNING	5	8s	0	7mm	3.57	100.00	0.00
RESCANNING	10	8s	0	7mm	3.51	100.00	0.00
RESCANNING	15	8s	0	7mm	3.61	100.00	0.00
RESCANNING	20	8s	0	7mm	3.57	100.00	0.00
RESCANNING	5	8s	90	7mm	3.61	100.00	0.00
RESCANNING	10	8s	90	7mm	3.47	100.00	0.00
RESCANNING	15	8s	90	7mm	3.55	100.00	0.00
RESCANNING	20	8s	90	7mm	3.31	100.00	0.00

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