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FULL PAPER

Are pitch and roll compensations required in all pathologies? A data analysis of 2945 fractions

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Objective: New linear accelerators can be equipped with a 6D robotic couch, providing two additional rotational motion axes: pitch and roll. These shifts in kilo voltage-cone beam CT (kV-CBCT) image-guided radiotherapy (IGRT) were evaluated over the first 6 months of usage of a 6D robotic couch-top, ranking the treatment sites for which the two compensations are larger for patient set-up.

Methods: The couch compensations of 2945 fractions for 376 consecutive patients treated on the PerfectPitch™ 6D couch (Varian® Medical Systems, Palo Alto, CA) were analysed. Among these patients, 169 were treated for brain, 111 for lung, 54 for liver, 26 for pancreas and 16 for prostate tumours. During the set-up, patient anatomy from planning CT was aligned to kV-CBCT, and 6D movements were executed. Information related to pitch and roll were extracted by proper querying of the Microsoft® SQL server (Microsoft Corporation, Redmond, WA) ARIA database (Varian Medical Systems). Mean values and standard deviations were calculated for all sites. Kolmogorov-Smirnov (KS) test was performed.

Results: Considering all the data, mean pitch and roll adjustments were $-0.10^\circ \pm 0.92^\circ$ and $0.12^\circ \pm 0.96^\circ$, respectively; mean absolute values for both adjustments were $0.58^\circ \pm 0.69^\circ$ and $0.69^\circ \pm 0.72^\circ$, respectively. Brain treatments showed the highest mean absolute values for pitch and roll rotations ($0.73^\circ \pm 0.69^\circ$ and $0.80^\circ \pm 0.78^\circ$, respectively); the lowest values of $0.36^\circ \pm 0.47^\circ$ and $0.49^\circ \pm 0.58^\circ$ were found for pancreas. KS test was significant for brain vs liver, pancreas and prostate. Collective corrections (pitch + roll) $>0.5^\circ$, $>1.0^\circ$ and $>2.0^\circ$ were observed in, respectively, 79.8%, 61.0% and 29.1% for brain and 56.7%, 39.4% and 6.7% for pancreas.

Conclusion: Adjustments in all six dimensions, including unconventional pitch and roll rotations, improve the patient set-up in all treatment sites. The greatest improvement was observed for patients with brain tumours.

Advances in knowledge: To our knowledge, this is the first systematic evaluation of the clinical efficacy of a 6D Robotic couch-top in CBCT IGRT over different tumour regions.

INTRODUCTION

Modern radiotherapy technologies allow high accuracy in patient positioning and delivery. In particular, increasing the patient set-up, accuracy could lead to margin reduction.¹ In this context, image-guided radiotherapy (IGRT) systems typically use a four degrees of freedom couch, in which the repositioning is performed on the three translational axes (i.e. longitudinal, lateral and vertical), as well as the couch rotation angle. Therefore, a compromise should be performed to take into account possible residual pitch and roll rotations.

Recent improvements in couch technology allow the inclusion of the two additional rotational axes. Nowadays, six degrees of freedom (6DoF) couches are available on the market. Several groups have shown that all six axes are

extensively used for the patient set-up in clinical routine,^{2–7} revealing that 6DoF couches are useful in all situations. However, not all radiotherapy machines are equipped with a 6DoF couch; therefore, a ranking of the sites that can benefit the most from the 6DoF couch is required.

The pitch and roll compensations in kilo voltage-cone beam CT (kV-CBCT) IGRT over the first 6 months of usage of the new EDGE™ linear accelerator (Varian® Medical Systems, Palo Alto, CA), equipped with a 6DoF couch, were evaluated. The data were analysed in order to classify the treatment sites for which the pitch and roll compensations are greater.

METHODS AND MATERIALS

The EDGE linear accelerator was recently installed at Humanitas Cancer Center. This linear accelerator is equipped

with 120HD® multileaf collimator. It can deliver beams with three energies (6 and 10 MV flattened-filter-free and the standard 6 MV) and has the imaging system XI. This last system consists of the portal imager PV-aS1200 for megavoltage (MV) portal and cine images, the kV source-detector system, which allows acquisition of radiographic and fluoroscopic images, and CT projections that can be reconstructed as three-dimensional (3D) kV-CBCT images, and 4D-CBCT. Moreover, the Optical Surface Monitoring System (Varian Medical Systems) for cranial lesion and Calypso® system (Varian Medical Systems) for extracranial lesions can be adopted as part of the IGRT procedure. Finally, EDGE is equipped with the new PerfectPitch™ 6DoF couch (Varian Medical Systems), allowing the patient repositioning based on the three geometrical and the three rotational axes, simultaneously. 6DoF couch shifts are applied to match kV-CBCT and planning CT (Figure 1).

Kilo voltage-cone beam CT-based image-guided radiotherapy

During kV-CBCT scan, the kV source-detector couple rotates completely around the targeted anatomy. The scanning software collects the data and reconstructs it to produce a digital 3D reconstruction. Owing to its rotational movement, care should be taken to ensure that kV-CBCT acquisition is performed without the couch colliding with the accelerator or the imaging arms. For this reason, kV-CBCT can only be acquired with the couch positioned at 0°. Among other options, an automated 3D–3D matching between the acquired kV-CBCT and the reference CT is available. This can be performed on all the six couch axes (vertical, longitudinal, lateral, rotation, pitch and roll), choosing a proper range of Hounsfield units to optimize the matching.

Imaging isocentre calibration procedure

The IsoCal calibration is the approach utilized by EDGE to calibrate the imager isocentres, finding the treatment isocentre (MV), and then relate the kV isocentre to this location.⁸ It uses a partial transmission plate (mounted on the linear accelerator head) and the isocentre calibration phantom consisting of 16 tungsten bearing balls arranged in a special pattern and embedded in a plastic cylinder, mounted on the front end of the treatment couch through a dedicated adapter. It calibrates the MV detector and kV detector arms to the radiation isocentre and calculates the

corrections for the longitudinal and lateral positions of both the MV and kV imagers for each gantry angle (typically 120 different positions). This is performed by following a pre-defined procedure and image sequence in the linear accelerator service mode. The IsoCal system was calibrated during the EDGE commissioning and verified monthly.

PerfectPitch performance tests

The new 6DoF couch adds a two degrees of freedom module to the pedestal of the already existing four degrees of freedom couch. The PerfectPitch couch was characterized by Schmidhalter *et al.*⁹ The same procedure during the commissioning and acceptance tests was adopted in this work.

In particular, regarding the pitch and roll, the possibility to move the couch with a known rotation was tested. The two degrees of freedom can pitch and roll in a range of $\pm 3^\circ$. Ten different rotational shifts in the range -3° to $+3^\circ$ were applied, with and without an additional load of 100 kg, simulating the weight of a patient. Shifts were verified using a digital inclinometer. Furthermore, an imaging method was also used to verify the correspondence of 6D shifts and kV-CBCT. A simulation CT of the Marker Block (a parallelepiped phantom with five internal radio-opaque markers provided with the Varian Linacs) was acquired as reference. Furthermore, mechanical wedges were used for creating 10 pre-determined pitch and roll rotations of the Marker Block, and a different CT scan was acquired for each position of the phantom. All images were loaded on the EDGE console, and kV-CBCT was executed for 6D matching. Residual errors were evaluated.

Patient data collection

Data from the first 6 months of the EDGE usage (April 2014 to September 2014) were collected. In particular, the couch compensations of 2945 fractions from 376 patients treated on the PerfectPitch 6DoF couch were analysed. All patients but four, independently from number of fractions and dose per fraction, had a personal mask used both during the CT simulation and during the delivery. Of these patients, 169 were treated for brain tumour, 111 for lung, 54 for liver, 26 for pancreas and 16 for prostate (Table 1). In particular, abdominal compression was used for patients with liver and pancreas tumours,¹⁰ while no compression was used for lung.¹¹ During set-up, the patient anatomy from planning CT was aligned to kV-CBCT. EDGE, like the other Varian linear accelerators, has two CBCT acquisition scan protocols: “head” (100 kV, 400 mAs, full fan, rotation acquisition: 200°, maximum scan diameter: 26.3 cm, maximum scan range: 18.6 cm) and “pelvis” (125 kV, 1056 mAs, half fan, rotation acquisition: 360°, maximum scan diameter: 46.5 cm, maximum scan range: 18.6 cm). All data but patients with brain tumours were acquired using “pelvis” acquisition modality.

Online automatic rigid registration was performed in 6DoF using the default algorithm available on the console based on bones matching for all the regions considered. Online manual matching performed by the radiation oncologist and/or a technician, in accordance to the region procedure, was then performed. The bones were used for brain tumours; the internal target volume generated by the simulation 4D-CT was used for lung tumours;

Figure 1. Pitch and roll directions for the PerfectPitch™ couch (Varian® Medical Systems, Palo Alto, CA).

Table 1. Patients' radiotherapy schemes for brain, lung, prostate, pancreas, liver and prostate tumours considered in the present analysis

Organ	Number of Patients	Number of fractions	Dose per Fraction (Gy)	Total Dose (Gy)
Brain	88	1	12.00–25.00	12.00–25.00
	35	2–5	5.00–10.00	20.00–40.00
	46	>5	1.80–5.00	25.00–60.00
Lung	66	3–4	12.00–20.00	48.00–60.00
	34	5–8	6.00–12.00	48.00–60.00
	11	>8	2.00–3.00	30.00–56.00
Liver	24	3	15.00–25.00	45.00–75.00
	30	>3	3.00–10.50	45.00–63.20
Pancreas	23	4–6	7.00–10.00	35.00–45.00
	3	28	1.80–2.00	50.40–56.00
Prostate	12	4–5	7.00–9.50	35.00–38.00
	4	28	2.55–2.66	71.40–74.20

the whole liver and, when available, internal markers were used for hepatic tumours; the target area, the calcifications and/or stents in aorta were utilized for pancreas tumour; the prostate location was used for prostate tumour. Finally, the shifts were sent to the EDGE couch and data were recorded into the ARIA database (Varian Medical Systems).

Data analysis

Information related to pitch and roll were extracted by proper querying of the Microsoft® SQL server (Microsoft, Redmond, WA) ARIA database (Varian Medical Systems). For analysis purpose, pitch and roll angles $<0^\circ$ were reported using negative values (*i.e.* 358° was considered as -2°).

Mean values and standard deviations were calculated for all sites. Data were considered both with and without sign (*i.e.* absolute values). Percentages of patients with absolute pitch plus roll rotation shifts $>0.5^\circ$, $>1.0^\circ$ and $>2.0^\circ$ were collected to summarise the data into a single value. This value does not have a physical meaning and was used only for a representation purpose.

The database was analysed to find any possible trend/difference related to months, number of fractions, dose per fraction or total fraction number.

A two-sample non-parametric Kolmogorov–Smirnov (KS) test was performed to verify the significance of the differences between the various groups in terms of absolute values. Owing to the high number of data collected, differences were considered significant with p -values <0.01 .

RESULTS AND DISCUSSION

To our knowledge, this is the first systematic evaluation of the pitch and roll compensations in kV-CBCT IGRT over different tumour sites. Patients with brain, lung, liver, pancreas and prostate tumours were considered without limitations on dose per fraction and total number of fractions. Furthermore, no limitation in target volume and shape was adopted. The PerfectPitch couch, mounted on the new EDGE platform, was used.

In particular, data from the first months of usage of EDGE in the Radiation Oncology Department of the Humanitas Clinical and Research Center were collected. All patients had personal masks to reduce set-up motion. The only exception was the non-hypofractionated prostate patients treated in 28 fractions (4 patients) for which a standard leg support was used. Patients with abdominal lesions (*i.e.* liver and pancreas) had abdominal compressors for minimizing the breathing-induced internal motion.¹⁰

As a pre-requisite, the isocentre imaging system and the PerfectPitch couch accuracies were evaluated. In particular, the imaging system XI was verified to maintain the isocentre inaccuracy to <0.5 mm. During monthly verification, the isocentre displacement verified with Isocal was within 0.5 mm. The maximum pitch and roll rotation residual errors, calculated using the inclinometer, were 0.04° and 0.03° , respectively. These data are in agreement with the results of Schmidhalter et al.⁹ The maximum marker block residual error evaluated using the kV-CBCT was 0.04° .

Once the EDGE ability to manage the pitch and roll rotations was verified, the study focused on the co-registration data derived from the treated patients. EDGE has the advantage of a good integration of the PerfectPitch into the platform system and thus allows the data to be easily extracted and analysed.

Considering all the patients, mean pitch and roll adjustments were $-0.09^\circ \pm 0.94^\circ$ and $0.11^\circ \pm 1.00^\circ$, respectively, revealing no preferential direction for pitch and roll rotations (*i.e.* no systematic errors). Mean absolute values for both adjustments were $0.63^\circ \pm 0.70^\circ$ and $0.68^\circ \pm 0.74^\circ$ for pitch and roll rotations, respectively. These results are in agreement with the data found in the literature.^{2,4,5,9} Table 2 reports all the data analyses stratified by treatment sites. In particular, brain treatments showed the highest mean absolute values with $0.73^\circ \pm 0.69^\circ$ and $0.80^\circ \pm 0.78^\circ$ for pitch and roll rotations, respectively; the lowest values were found for pancreas with $0.36^\circ \pm 0.47^\circ$ and $0.49^\circ \pm 0.58^\circ$. KS test was significant for brain vs all the other organs. The sum of pitch and roll rotations resulted in corrections $>0.5^\circ$, $>1.0^\circ$ and $>2.0^\circ$ in, respectively, 79.8%, 61.0% and 29.1% for brain

Table 2. Absolute (abs) pitch and roll adjustments (mean $\pm$ standard deviation) for brain, lung, prostate, pancreas, liver and prostate tumours

Organ	Pitch ($^{\circ}$)	Roll ($^{\circ}$)	Pitch abs ($^{\circ}$)	Roll abs ($^{\circ}$)	(P + R) $> 0.5^{\circ}$ (%)	(P + R) $> 1^{\circ}$ (%)	(P + R) $> 2^{\circ}$ (%)
Brain (B)	-0.20 ± 0.99	0.11 ± 1.11	0.73 ± 0.69	0.80 ± 0.78	79.8	61.0	29.1
Lung (L)	0.06 ± 0.95	-0.07 ± 0.97	0.60 ± 0.74	0.64 ± 0.74	64.5	50.2	24.4
Pancreas (P)	-0.19 ± 0.56	0.32 ± 0.69	0.36 ± 0.47	0.49 ± 0.58	56.7	39.4	6.7
Liver (Li)	-0.22 ± 0.84	0.30 ± 0.85	0.49 ± 0.72	0.56 ± 0.70	56.4	41.7	20.5
Prostate (Pr)	0.26 ± 0.91	0.24 ± 0.73	0.61 ± 0.72	0.54 ± 0.55	68.8	47.5	18.1
Total (T)	-0.09 ± 0.94	0.11 ± 1.00	0.63 ± 0.70	0.68 ± 0.74	70.1	53.0	24.2

(P + R), sum of the absolute pitch and roll rotations.

Collective corrections (*i.e.* pitch + roll) $>0.5^{\circ}$, $>1.0^{\circ}$ and $>2.0^{\circ}$ for the same sites are also reported. The *p*-values of the Kolmogorov-Smirnov test between the different groups of patients were: for B-L, B-P, B-Li and B-Pr ($p < 0.01$); and for L-P, L-Li, L-Pr, P-Li, P-Pr and Li-Pr ($p > 0.01$).

and 56.7%, 39.4% and 6.7% for pancreas. Figure 2 shows the box plot representation of the data.

According to the internal procedure, the Radiation Therapy Technologists should enter into the bunker, when a compensation $>2^{\circ}$ in one direction is requested, to verify the movements and perform a dry run before starting the delivery. In our opinion, this process helps in understanding whether major problems are introduced in the positioning procedure. In particular, in 12 cases (*i.e.* 0.4%), compensations $>2.5^{\circ}$ in both pitch and roll directions were requested. In the cases with number of fractions ≥ 10 (10 patients), the doses were delivered without further investigations. For the other two cases with >10 fractions (both cases were patients with brain tumour), a new reposition procedure was performed. In one case, a wrong

headrest had been used. After the second CBCT, the compensations were $<1^{\circ}$ in both directions.

The major pitch and roll corrections required after kV-CBCT for head may be explained by considering the wider range of movements achievable by the head-neck junction (Figure 3). The results were the opposite of the Schmidhalter data obtained with BrainLAB ExacTrac® X-Ray 6D system (BrainLAB, Feldkirchen, Germany).² They found, using the 2D–2D kV imaging co-registration approach, the variance of the distribution of the initial set-up errors for the extracranial cases to be higher than for the cranial cases. They stated that reasons for this could be (i) the different immobilization strategy for the cranial and extracranial region and (ii) the deformability of the anatomy in the target region. In this study, a similar immobilization strategy

Figure 2. Box plot representation. The five organs are reported on the y-axis, whereas on the x-axis, the sum of the absolute values of pitch and roll rotations are shown. For each organ, the 75th and 25th percentiles are represented by the right and left edges of the “rectangular” box, while the central line is the median value. The data range and the outliers are reported, too.

Figure 3. Head-neck junction motilities in the three rotational axes: (left) pitch, (centre) rotation and (right) roll.

for head and body cases was adopted, with patients immobilized with a thermoplastic mask. Furthermore, the body anatomy deformability is reduced using the abdominal compressor. Finally, authors underline how the kV-CBCT, simulation CT matching, should be, in principle, more accurate than simple two projections based on bony anatomy, in particular in case of solid tumours. In this context, Dhabaan et al¹² suggested a volumetric imaging system (e.g. CBCT) positioning in frameless stereotactic radiotherapy.

Other investigators have reported data regarding difference in using 6DoF and only 4DoF.^{12–14} They reported a loss of dose coverage of up to 5% to the planning target volume (PTV) if all three rotational shifts were not applied.¹³ In another study,¹⁴ the effect of applying 4DoF instead of 6DoF shifts was examined when treating stereotactic body radiation therapy cases, such as spine radiosurgery. The authors reported significant reduction in the PTV dose coverage if pitch and roll rotational shifts were not taken into account. They also reported that the size and shape of PTV play a vital role in loss of dose coverage. For example, they showed that the exclusion of roll and pitch (1.65° and 1.23°, respectively) will induce an important dose coverage reduction for highly irregular tumours from 57.2% to 49.1% at 10-Gy dose level. Based on these publications, it is clear that adjusting only for 4DoF may, in some cases, lead to a significant reduction in PTV coverage. As stated by Dhabaan et al,¹² while it may not be required to make the pitch and roll adjustments in all cases, it would be difficult to establish, while the patient is on the treatment couch, whether a particular rotational adjustment would make a significant difference in PTV coverage. Since performing the additional match with 6DoF only adds a relatively short

amount of time to the overall process, we suggest making the precise match in all cases.

In our series, no significant trend along the 6 months included in the evaluation was found. No significant differences or trends for doses per fraction, number of fractions or other parameters were found either. A possible explanation could be the type of patients treated on the EDGE linear accelerator in our department. Other authors have observed a correlation between the applied corrections and the number of fractions probably related to the body shrinkage.^{15,16} In our case, the numbers of fractions is usually <8 (Table 1), and thus, the shrinkage has a reduced influence.

This study was focused on the magnitude of the corrections in different anatomical sites, assuming that the pitch and roll rotations have a direct impact on the dose distribution distortion in all treatment sites. Some differences were observed among the various regions, but the suggestion is, when possible, to have a precautionary approach and always apply all the shifts. Within given treatments, other parameters, e.g. target shape and volume, or dose conformity to the target, could have an impact on the compensations and should be further investigated and taken into account for each individual case.

CONCLUSION

Adjustments in all six dimensions, including unconventional pitch and roll rotations, improve the patient set-up for all regions. Maximum pitch and roll shifts were obtained in brain tumours, and therefore, it is suggested that 6D robotic couch implementation on brain tumours is used, where resources are available.

REFERENCES

1. Verellen D, De Ridder M, Linthout N, Tournel K, Soete G, Storme G. Innovations in image-guided radiotherapy. *Nat Rev Cancer* 2007; **7**: 949–60. doi: [10.1038/nrc2288](https://doi.org/10.1038/nrc2288)
2. Schmidhalter D, Malthaner M, Born EJ, Pica A, Schmucking M, Aebbers DM, et al. Assessment of patient setup errors in IGRT in combination with a six degrees of freedom couch. *Z Med Phys* 2014; **24**: 112–22. doi: [10.1016/j.zemedi.2013.11.002](https://doi.org/10.1016/j.zemedi.2013.11.002)
3. Laursen LV, Elstrom UV, Vestergaard A, Muren LP, Petersen JB, Lindegaard JC, et al. Residual rotational set-up errors after daily cone-beam CT image guided radiotherapy of locally advanced cervical cancer. *Radiother Oncol* 2012; **105**: 220–5. doi: [10.1016/j.radonc.2012.08.012](https://doi.org/10.1016/j.radonc.2012.08.012)
4. Kaiser A, Schultheiss TE, Wong JY, Smith DD, Han C, Vora NL, et al. Pitch, roll, and yaw variations in patient positioning. *Int J Radiat Oncol Biol Phys* 2006; **66**: 949–55. doi: [10.1016/j.ijrobp.2006.05.055](https://doi.org/10.1016/j.ijrobp.2006.05.055)
5. Hyde D, Lochray F, Korol R, Davidson M, Wong CS, Ma L, et al. Spine stereotactic body radiotherapy utilizing cone-beam CT image-guidance with a robotic couch: intrafraction motion analysis accounting for all six degrees of freedom. *Int J Radiat Oncol Biol Phys* 2012; **82**: e555–62. doi: [10.1016/j.ijrobp.2011.06.1980](https://doi.org/10.1016/j.ijrobp.2011.06.1980)

6. Dahele M, Verbakel W, Cuijpers J, Slotman B, Senan S. An analysis of patient positioning during stereotactic lung radiotherapy performed without rigid external immobilization. *Radiother Oncol* 2012; **104**: 28–34. doi: [10.1016/j.radonc.2012.03.020](https://doi.org/10.1016/j.radonc.2012.03.020)
7. Yuen Kan Ngar D, Lok-Man Cheung M, Koon-Ming Kam M, Poon WS, Tak-Cheung Chan A. A novel compound 6D-offset simulating phantom and quality assurance program for stereotactic image-guided radiation therapy system. *J Appl Clin Med Phys* 2014; **14**: 4297.
8. Gao S, Du W, Balter P. Evaluation of IsoCal imaging isocenter calibration system for varian OBI machines. *Med Phys* 2012; **39**: 3604. doi: [10.1118/1.4734633](https://doi.org/10.1118/1.4734633)
9. Schmidhalter D, Fix MK, Wyss M, Schaer N, Munro P, Scheib S, et al. Evaluation of a new six degrees of freedom couch for radiation therapy. *Med Phys* 2013; **40**: 111710. doi: [10.1118/1.4823789](https://doi.org/10.1118/1.4823789)
10. Wunderink W, Méndez Romero A, de Kruijff W, de Boer H, Levendag P, Heijmen B. Reduction of respiratory liver tumor motion by abdominal compression in stereotactic body frame, analyzed by tracking fiducial markers implanted in liver. *Int J Radiat Oncol Biol Phys* 2008; **71**: 907–15
11. Bouilhol G, Ayadi M, Rit S, Thengumpallil S, Schaerer J, Vandemeulebroucke J, et al. Is abdominal compression useful in lung stereotactic body radiation therapy? A 4DCT and dosimetric lobe-dependent study. *Phys Med* 2013; **29**: 333–40. doi: [10.1016/j.ejmp.2012.04.006](https://doi.org/10.1016/j.ejmp.2012.04.006)
12. Dhabaan A, Schreiber E, Siddiqi A, Elder E, Fox T, Ogunleye T, et al. Six degrees of freedom CBCT-based positioning for intracranial targets treated with frameless stereotactic radiosurgery. *J Appl Clin Med Phys* 2012; **13**: 3916. doi: [10.1120/jacmp.v13i6.3916](https://doi.org/10.1120/jacmp.v13i6.3916)
13. Gevaert T, Verellen D, Engels B, Depuydt T, Heuninckx K, Tournel K, et al. Clinical evaluation of a robotic 6-degree of freedom treatment couch for frameless radiosurgery. *Int J Radiat Oncol Biol Phys* 2012; **83**: 467–74. doi: [10.1016/j.ijrobp.2011.05.048](https://doi.org/10.1016/j.ijrobp.2011.05.048)
14. Schreiber E, Fox T, Crocker I. Dosimetric effects of manual cone-beam CT (CBCT) matching for spinal radiosurgery: our experience. *J Appl Clin Med Phys* 2011; **12**: 132–41.
15. Lang S, Linsenmeier C, Brown ML, Cavelaars F, Tini A, Winter C, et al. Implementation and validation of a new fixation system for stereotactic radiation therapy: an analysis of patient immobilization. *Pract Radiat Oncol* 2015; pii: S1879–8500(15)00094-6. doi: [10.1016/j.prro.2015.03.007](https://doi.org/10.1016/j.prro.2015.03.007)
16. Mongioj V, Orlandi E, Palazzi M, Deponti E, Marzia F, Stucchi C, et al. Set-up errors analyses in IMRT treatments for nasopharyngeal carcinoma to evaluate time trends, PTV and PRV margins. *Acta Oncol* 2011; **50**: 61–71. doi: [10.3109/0284186X.2010.509108](https://doi.org/10.3109/0284186X.2010.509108)