THE IMPORTANCE OF ADDITIONAL GEOMETRICAL VERIFICATION WITH AUTO BEAM HOLD FUNCTION IN PROSTATE CANCER IRRADIATION

by

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This paper aims to determine the need for additional imaging verification when using the auto beam hold function in radiotherapy of prostate cancer patients with inserted gold fiducial markers. Forty patients who underwent irradiation of the prostate and twenty with prostate and pelvic lymph node radiotherapy were included in the retrospective study. Intrafraction shifts during irradiation were compared with the auto beam hold function in the translational directions. The function was used with time tracking (5 seconds), a tolerance limit for marker deviations (4 mm), and bone structures in the large irradiation field (5 mm).
The need for additional image verification was higher in the larger irradiation field group. When translational shifts were analysed, a statistically significant difference in the vertical direction was found in the group with only prostate irradiation (p = 0.013). A statistically significant difference in the lateral direction was found in the group with a larger irradiation field (p = 0.021). Translational shifts were not statistically significantly different between the two groups (p > 0.05). Conclusion: Intrafraction shifts of the prostate increase the need for additional imaging verification. The use of the auto beam hold function is effective in reducing errors.

Key words: prostate cancer, radiotherapy, intrafraction movement, 2-D kV imaging in radiotherapy, auto beam hold function

INTRODUCTION

Different verification systems allow the position of the prostate to be determined within a few millimetres before each irradiation [1]. Intrafraction shifts occur during irradiation due to patient movement or internal anatomical shifts due to physiological processes. To reduce the discrepancies between interfraction and intrafraction shifts, several systems have been developed to ensure reproducible patient positioning during irradiation [2]. Due to the location of the prostate as well as the bladder and rectum status (full or empty), accidental changes in its position can occur. Rotation, twisting, or changes in shape can also occur, which makes it difficult to accurately position the patient and perform the irradiation. The clinical target volume (CTV) plays an important role, often consisting of seminal vesicles and pelvic lymph nodes, which are known to move in relation to each other, in addition to the prostate [3]. The rectum plays the most important role in a volume change, with the largest rotational shifts [4]. The rectum, bladder, and penis are organs at risk near the prostate and are partly involved in the planning target volume (PTV) [5]. The gap between the CTV and PTV represents the boundary where the dose to healthy tissue such as the rectum and bladder is increased [3]. The key components in intrafraction shifts are rectum status and duration of irradiation. The duration of radiation is best reduced using volumetric modulated arc therapy (VMAT) and the use of flattening filter-free technique [5]. The size and shape of the target volume may vary over the course of treatment, and consideration should be given to expected shifts (*e. g.*, the urge to urinate with reduced urinary retention), expected variations in the shape and size of the target volume during the treatment process (*e. g.*, bladder, rectum), imprecision, or variations at patient set-up [6].

Image-guided radiation therapy (IGRT) has become the gold standard for the treatment of prostate cancer in radiotherapy, as it has improved control and reduced toxicity to the urinary tract and gastrointestinal tract. There are different IGRT strategies for pros-

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tate radiotherapy [7]. True Beam v2.5 (Varian) linear accelerator, which offers an advanced IGRT system with a motion tracking system, allows kV images to be acquired during radiation therapy using an on-board imager (OBI) [8]. The geometric imaging verification used for bone structures is 2-D imaging, while 3-D imaging with cone beam computed tomography (CBCT) is used for soft tissue visualisation [9, 10]. Both imaging modalities offer visualisation of prostate movement in relation to the bone anatomy with the insertion of gold fiducial markers in the prostate. This allows us to consider the interfraction shifts of the prostate during daily verification.

The CBCT offers better visualisation of soft tissues, but the ionizing dose, received by the patient is much higher, while kV imaging has a lower dose and reduces image acquisition and alignment time. In the case of a prostate with fiducial markers, three to four markers are inserted into the prostate using ultrasound before starting radiation treatment [11]. The auto beam hold (aBH) function allows the analysis of 2-D kV images acquired during irradiation, where the system automatically detects markers and pauses the irradiation [12]. The software uses a search algorithm. This finds the location of the marker in each triggered image and determines whether it is within predefined tolerance limits from the expected location. The software package allows the user to define the frequency of triggering of the kV images based on various criteria such as time, monitor units, and gantry angle of the linear accelerator. The user also selects a predefined tolerance limit of the markers with the expected position. The expected area is shown as a circle and the defined marker position as a cross. The circle and cross are shown in three colours; green, if the marker is within the defined tolerance limits, fig. 1, yellow if the marker is not detected by the software, and, red, if the marker is outside the defined tolerance limits (in electronic form). The visualisation allows the user to qualitatively check for any marker movement during irradiation [13]. Irradiation is automatically stopped if the difference in marker position exceeds the user-defined tolerance [8]. This study aimed to determine the need for additional geometrical 2-D kV imaging verification when aBH function is used in irradiating prostate cancer patients.

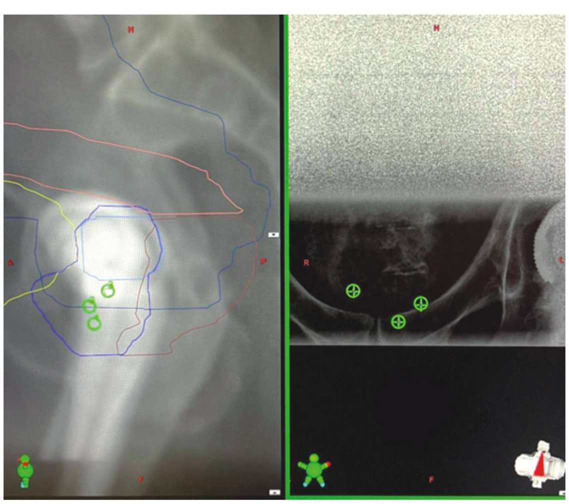

Figure 1. Marker position evaluation using the aBH method – all markers are within the tolerance limits

MATERIALS AND METHODS

The 60 patients who received radical radiotherapy treatment for prostate cancer between the years 2020 and 2022 were included in this retrospective study. Patients were divided into two groups. The first group consisted of 40 patients who underwent irradiation of the prostate, while the second group consisted of 20 patients who underwent irradiation of the prostate and pelvic lymph nodes. All included patients had gold fiducial markers inserted into the prostate and underwent irradiation with the VMAT irradiation technique on the TrueBeam v2.5 linear accelerator (Varian). Intrafraction shifts recorded with the aBH function during irradiation were compared. The displacements were recorded in the translational directions, that allow the treatment couch to move in the longitudinal direction – LNG (superior and inferior), lateral direction – LAT (left and right), and vertical direction – VRT (anterior and posterior). The data were accessed from the ARIA computer system in an offline review window. The protocol used in patients with gold fiducial markers in the prostate was: all patients empty their bladder and drink 0.5 litres of water 45 min before irradiation. The 3-D OBI-CBCT is used for the first three days at the start of irradiation, then once a week for a check-up of the anatomical structures. The 2-D OBI imaging is performed for the remaining days. During the irradiation, 2-D OBI imaging is used as an additional correction to the aBH function, in case of patient or prostate displacement. The aBH function was applied with a time-tracking of 5 seconds and a tolerance limit for marker deviation of 4 mm. In patients who received prostate and pelvic lymph node irradiation, the tolerance for bone structure deviation was 5 mm. In case of marker dropout outside the predefined tolerance limit during irradiation (intrafraction displacement), the irradiation was automatically paused. This was followed by a 2-D OBI imaging verification to reset the patient in the isocentre and resume irradiation. The number and size of intrafraction shifts in the translational directions were analysed. For data analysis and evaluation, Microsoft Excel 2016 and the Statistical Package for the Social Sciences, version 26.0 (SPSS Inc., Chicago, IL, USA) were used. Statistically significant changes were assessed at a *p*-value of $p \leq 0.05$.

RESULTS

The 60 radically treated prostate cancer patients with gold fiducial markers inserted were included in this retrospective study. To monitor intrafraction shifts, the need for additional imaging verification (2-D OBI) due to patient shifts was analysed regarding the size of the irradiation field (prostate/prostate and pelvic lymph node area). The smaller irradiation field (prostate only) measured 7.60 cm × 7.20 cm on average, while the average size of the larger irradiation field (prostate and lymph nodes) was 13.40 cm × 22.70 cm. The analysis was divided into two parts:

– Part 1: Analysis of the number of additional geometrical image verifications per fraction (if there was patient movement during a fraction).

– Part 2: Analysis of the total number of additional image verifications (how many times additional image verifications had to be performed during the total duration of irradiation – all fractions).

The analysis showed, fig. 2, that there is no statistically significant difference between the two parts ($p > 0.05$).

Regarding the number of additional image verifications per fraction, it was observed that patients, receiving irradiation of the prostate and pelvic lymph nodes had a higher minimum and maximum number of additional image verifications per fraction (minimum = 5 and maximum = 26), compared to patients irradiated to the prostate only, with minimum = 2 and maximum = 21. The results are shown in fig. 3.

A higher minimum and maximum total number of additional imaging verifications can also be observed in patients irradiated to the prostate and pelvic lymph nodes (minimum = 5 and maximum = 57), while in patients irradiated to the prostate only, the total values are lower (minimum = 4 and maximum = = 45), fig. 4.

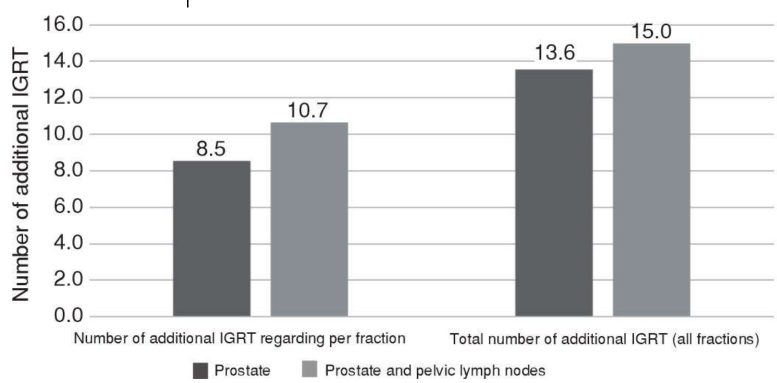

Figure 2. Number of additional geometrical image verification according to irradiation region per fraction and for all fractions

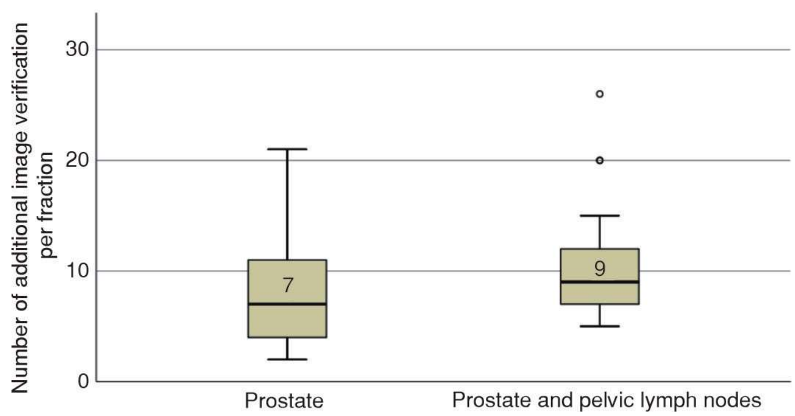

Figure 3. Number of additional geometrical image verifications per fraction

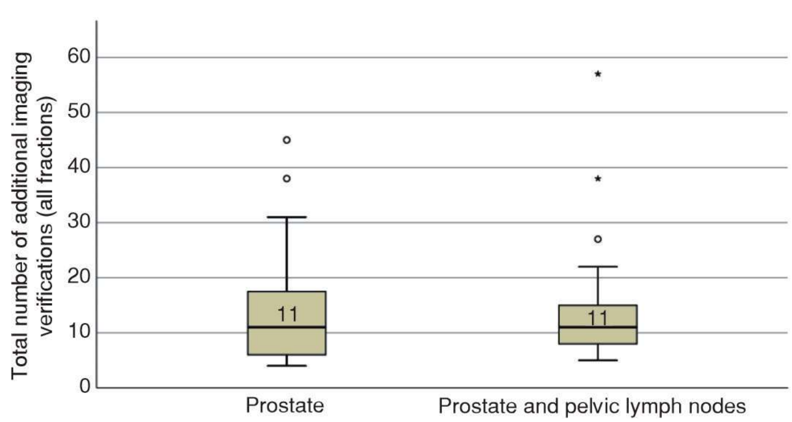

Figure 4. Total number of additional IGRT (all fractions)

The translational shifts were analysed to determine whether there were statistically significant differences in the vertical, longitudinal, and lateral directions between the two groups of patients. In the group of patients undergoing prostate-only irradiation, we found that there was a statistically significant difference in the vertical direction (p = 0.013), whereas there were no statistically significant differences in the longitudinal and lateral directions ($p > 0.05$). The vertical shifts were larger in the anterior direction than in the posterior direction. The results are shown in fig. 5.

In the group of patients, who received irradiation of the prostate and pelvic lymph nodes, statistically significant differences in the lateral direction ($p = 0.021$) were observed, whereas there were no statistically significant differences in the longitudinal and vertical directions ($p > 0.05$). The lateral shifts were larger in the left direction than in the right direction, fig. 6.

The magnitudes of translational shifts were compared between the two groups of patients. The analysis showed, fig. 7, no statistically significant differences between the two groups in the vertical, longitudinal, or lateral directions ($p > 0.05$).

DISCUSSION

The study aimed to determine the need for additional imaging verification with a 2-D OBI system when using aBH function in the irradiation of prostate cancer patients with inserted gold fiducial markers. Translational shifts were analysed in 40 patients who underwent prostate irradiation and in 20 patients who underwent irradiation of the prostate and pelvic lymph node region.

The need for additional geometrical verification due to patient movement during irradiation per frac-

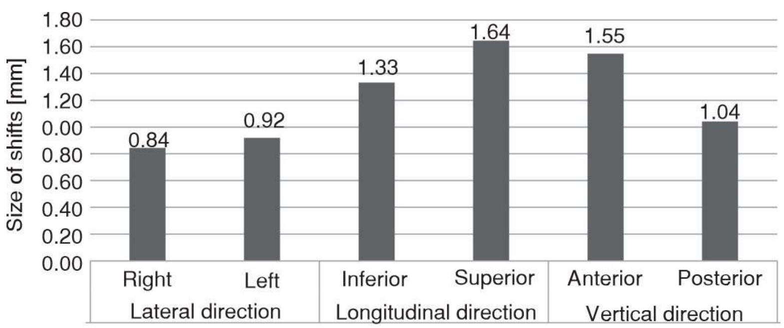

Figure 5. Prostate average shifts in lateral (right-left), longitudinal (inferior, superior), and vertical (anterior, posterior) directions

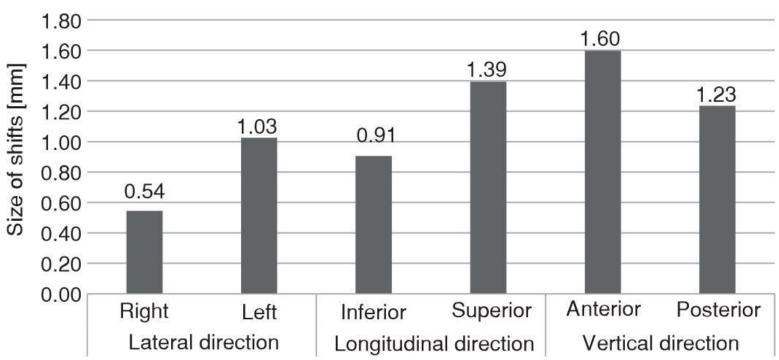

Figure 6. Prostate and pelvic lymph nodes average shifts in lateral, longitudinal, and vertical directions

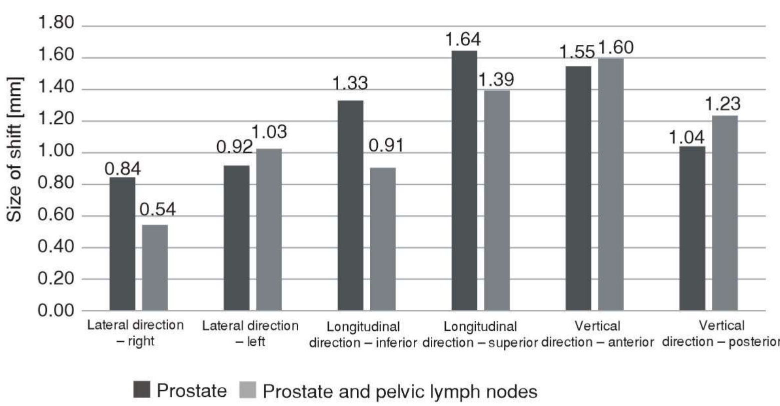

Figure 7. Average translational shifts (prostate/prostate and pelvic lymph nodes) in all directions

tion of irradiation and the total number of additional imaging verifications (all fractions) was evaluated. No statistically significant differences were found. In both parts of the analysis, patients who underwent irradiation of the prostate and pelvic lymph nodes had more additional image verifications. It can be assumed that the larger irradiation field and patient movement during irradiation will increase the need for additional image verification with the 2-D OBI system. The 2-D kV imaging system is the method of choice and provides satisfactory results. If there are gold fiducial markers present, there is no need for additional CBCT imaging, which significantly affects the duration of irradiation [14]. Also, the minimum and maximum values for both analyses can be seen in figs. 3 and 4, indicating that the need for additional image verification is higher in patients who have undergone irradiation of the prostate and pelvic lymph node region. To our knowledge, this difference has not been specifically discussed in any other study and can be further explored.

This was followed by an analysis of translational shifts in patients who underwent prostate irradiation. The largest mean shifts were in the longitudinal direction, in a superior direction. Similar results were obtained in a study by authors Chasseray and Marnouche, except that the shifts were larger in the inferior direction [15, 16]. The difference between patients who underwent prostate only and between those who underwent prostate and lymph node irradiation was highest in the inferior direction in our study as well. Statistically significant differences were perceived in the vertical direction. The shifts were larger in the anterior direction.

In patients who underwent irradiation of the prostate and pelvic lymph nodes, translational shifts were statistically significant in the lateral direction, and larger in the left direction. The largest perceived shifts were found in the vertical direction, namely in the anterior direction. Translational shifts were also compared between the two groups, where the analysis showed that there were no statistically significant differences in either direction. The smallest difference in mean shift between the two groups was in the vertical direction, namely in the anterior direction, while the largest difference in mean displacement between the two groups was in the longitudinal direction, namely in the inferior direction. In both groups, the larger shifts occurred in the lateral direction to the left. Ingrosso *et al*. in their study from 2019 state that larger shifts to the left side occur when the rectum increases in volume, which pushes the prostate to the left. The same study also discusses the role of organ anatomy in vertical shifts – those deviations were greatest when irradiating the prostate and the pelvic lymph nodes [17]. During irradiation, an increase in bladder volume pushes the prostate in the posterior direction, while a decrease in bladder volume causes a displacement of the prostate in the anterior direction. Based on the statistical analysis of the data from our study and the findings of other authors [15, 16] we can confirm that the prostate moves distinctly more in the vertical and longitudinal directions during irradiation.

For quality irradiation of prostate cancer, it is necessary to use modern verification equipment and, in the case of larger irradiation fields or a higher number of fractions and consequent patient movement, additional geometrical verification during irradiation should be used, such as a 2-D OBI imaging system. This can significantly help reduce daily treatment uncertainties and implement online adjustments for each fraction, which has also been noted by other authors [3, 17].

In future research, dose values for additional imaging in radiotherapy could also be observed and a higher number of patients included in the study could give us even better results. It would also be preferable to use the same number of patients for smaller (prostate only) and larger (prostate and lymph nodes) irradiation fields. The influence of significant gating event on fraction delivery time should be considered in future research.

CONCLUSION

The aBH function allows the user to pause irradiation if gold fiducial markers in the prostate move outside the tolerance limits, thus ensuring more precise irradiation for prostate cancer and avoiding unnecessary irradiation of healthy tissues. Intrafraction shifts in prostate cancer irradiation increase the need for additional imaging verification, as this effectively reduces errors that occur during irradiation, which are mostly due to patient shifts. The additional 2-D kV imaging system is particularly important when the irradiation field is larger, as we demonstrated when comparing the irradiation field of the prostate only (smaller irradiation field) and the prostate with pelvic lymph nodes (larger irradiation field). A higher minimum and maximum total number of additional imaging verifications were observed in patients with larger irradiation fields (min = 5 and max = 57) than in patients with smaller irradiation fields (min = 4 and max = 45). Application of aBH with gold fiducial markers eliminates the need for additional CBCT imaging.

AUTHORS' CONTRIBUTIONS

V. Žager Marciuš: supervision, study design, methodology, draft preparation, statistical analysis; K. Salmič: study design, data collection; A. Matjašić: study design, writing, methodology review.

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ЗНАЧАЈ ДОДАТНЕ ГЕОМЕТРИЈСКЕ ВЕРИФИКАЦИЈЕ СА ФУНКЦИЈОМ АУТОМАТСКОГ ЗАДРЖАВАЊА ВАЗДУХА У ЗРАЧЕЊУ РАКА ПРОСТАТЕ

Рад има за циљ да утврди потребу за додатном верификацијом имиџинга при коришћењу функције аутоматског задржавања ваздуха у радиотерапији пацијената са карциномом простате са уметнутим златним фидуцијалним маркерима. У ретроспективну студију укључено је четрдесет пацијената који су подвргнути зрачењу простате и двадесет пацијената радиотерапијом простате и карличних лимфних чворова. Интрафракциони помаци током зрачења упоређени су са функцијом аутоматског задржавања ваздуха у транслационим правцима. Функција је коришћена са праћењем времена (5 секунди), границом толеранције за одступања маркера (4 mm) и коштаним структурама у великом пољу зрачења (5 mm).

Потреба за додатном верификацијом слике била је већа у већој групи поља зрачења. Када су анализирани транслациони помаци, утврђена је статистички значајна разлика у вертикалном правцу у групи са само зрачењем простате (p = 0,013). Статистички значајна разлика у бочном правцу утврђена је у групи са већим пољем зрачења (p = 0,021), док се транслациони помаци нису статистички значајно разликовали између две групе (p > 0,05).

Кључне речи: карцином простате, радиотерапија, интрафракциони покрет, 2-D kV сликање у радиотерапији, функција аутоматског задржавања ваздуха