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Evaluating Accufix Head and Neck Shoulder Immobilization for Head and Neck Radiation Therapy

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Abstract
The field of radiation therapy has seen significant advancements in treatment precision, such as proton therapy and intensity-modulated radiotherapy, often involving various immobilization devices for patient positioning and motion monitoring. However, the effectiveness of shoulder immobilization systems, particularly in the neck and shoulder regions, requires further investigation due to conflicting results and limited studies. This study aims to evaluate the accuracy and effectiveness of the Accufix™ Head and Neck Device shoulder cantilever depression system in reducing interfractional and intrafractional movement in head and neck cancer (HNC) patients. This device positions the head, neck, and shoulders, lowering the shoulders to precisely target head and neck tumors with radiation beams. Patient data was collected for 3 larynx cancer patients and 1 tongue cancer patient undergoing volumetric-modulated arc therapy (VMAT) radiation therapy at the Juravinski Cancer Centre. Patients were immobilized using a head and neck thermoplastic mask and an Accufix™ Head and Neck device. AlignRT, an optical surface monitoring system (OSMS), was utilized to track real-time body surface movements during treatment in 3 translation directions (AP: anterior-posterior, SI: superior-inferior, and LR: left-right) and 3 rotations (pitch, roll, and yaw). Interfractional shoulder positioning discrepancies were evaluated by conducting cone-beam computed tomography (CBCT) scan and planning computed tomography (CT) scan image registration in two anatomical locations: the target volume (T-IM) and the mid-clavicles (C-IM). Intrafractional motion across all patients remained low for both translational and rotational shifts, with 6.42% exceeding a 5mm margin and 0.02% exceeding a 3º margin, respectively. Differences between target TV-IM and C-IM remained within +/- 3mm of shifts for the majority of fractions. Little consistency was found between AlignRT data and C-IM data, with shifts ranging from 10mm to -5mm, attributed to the surface geometry and shape of the region of interest (ROI) we tracked. While shoulder immobilization using the Accufix™ system was found to be sufficient, AlignRT's accuracy in reproducing patient shoulder positioning was limited in our study. Factors influencing surface-guided systems, such as ROI size and location, need careful evaluation. Further studies on SGRT use compared to immobilization devices are needed to validate these findings and explore potential improvements.

Keywords: AlignRT; optical surface monitoring system; SGRT; IGRT; larynx cancer; tongue cancer; intrafraction motion; interfraction motion; cantilever depression system; shoulder immobilization

Introduction

Background

Cancer treatment has progressed exponentially in the past century, with the availability of chemotherapy, radiation therapy, and immunotherapy coming to light. Alongside other modalities, radiotherapy has proved to be effective and essential for treating cancer and in palliative care [1,2]. Linear accelerators deliver photons into the body, ionizing biomolecules and damaging cellular DNA directly & indirectly, often leading to cell death [3]. Precise treatment relies on careful planning, accurate patient positioning, and continuous monitoring to target cancer cells while sparing healthy tissue. Patient positioning can be quantified between fractions/doses (interfractional), as well as during treatment itself (intrafractional). Immobilization devices play an important role in both interfractional and intrafractional movement and can vary from thermoplastic masks, shoulder depression systems, vacuum bags, or body rests. Treatment approaches commonly involve employing diverse combinations of these devices. However, the optimal technique for maximizing dose accuracy while minimizing movement is contingent upon the section of the body evaluated [4]. Thus, evaluating the immobilization of the lower neck and shoulders is crucial for improving treatment accuracy in head and neck radiotherapy, as these regions are particularly prone to setup and motion errors.

Shoulder Immobilization Devices

Various immobilization devices have been used to minimize movement in patients with head and neck cancer (HNC). However, the use of various thermoplastic masks, head supports, and neck supports seem to have limited effects on movement in the lower neck and supraclavicular regions [5-7], save for an E-frame mask implemented by Fukao et al. [8]. This mask is specifically shaped like an "E", with three prongs on one side that clip into the treatment table, as opposed to a the more commonly used S-frame or U-frame mask. Shoulder immobilization systems, such as cantilever depression systems and vacuum cushions, have also been evaluated. A study comparing three systems—a five-point thermoplastic mask, a head-only mask with vacuum neck support and a shoulder cantilever board, and an eight-point thermoplastic mask with a vacuum cushion—found that the five-point mask alone resulted in fewer random and translational errors [9].

Regional Variations in Treatment Fractions

Interfractional movement is typically assessed through image registration of planning kilo-volt cone beam computed tomography (kVCBCT) and cone beam computed tomography (CBCT) scans, referencing bony anatomy [10]. Studies indicate that lower neck structures experience greater setup discrepancies, particularly when aligning to the C2 vertebrae, with the most variation noted in the anterior-posterior (AP) and superior-inferior (SI) directions [11,12]. Patients with lower isocenters show more significant changes in cervical spinal angles over time [13]. Research on headrests in conjunction with thermoplastic masks indicates inadequate immobilization in the neck region due to semi-independent skull movement with respect to the neck [6,14]. Consequently, larger setup margins for target volumes near shoulder levels are recommended to address significant dose perturbations as treatment progresses [15,16]. Neubauer et al. found that shifts could result in substantial dose losses, prompting adjustments to planning target volume (PTV) margins for neck region targets to improve dosimetric coverage of lower neck regions [12].

Intrafractional motion in stereotactic body radiation therapy (SBRT) is monitored using surface or image-guided techniques [17]. Limited studies on the region of interest (ROI) location's impact on intrafractional motion have yielded inconclusive results, revealing translational errors that vary due to rotational shifts [18,19]. Kang et al. found increased roll and pitch displacements over time with different mask types, but the relative effectiveness of upper versus lower spine immobilization remains unclear [19]. Notably, shifts in the neck region are greater than anticipated during treatment.

Current Objectives

Current literature suggests thermoplastic masks adequately immobilize the head but less so the neck and shoulder regions. Although shoulder systems aim to enhance immobilization, evidence supporting their effectiveness is scarce. Further comparative research is needed, especially concerning HNC patients. Additionally, studies on intrafractional motion in the lower neck and shoulder areas are limited and inconsistent. Deviations from planning images often exceed PTV and setup margins, highlighting the need for re-evaluation of institutional margins relative to immobilization accuracy. To address these gaps, our study will evaluate the shoulder cantilever depression system's effectiveness in reducing interfractional and intrafractional movement in larynx and tongue cancer patients. Using AlignRT, a clavicle-based ROI will measure 6D deviations. Despite previous validation of AlignRT's Optical Surface Monitoring System (OSMS), little research exists on its application for larynx cancer patients, prompting this investigation into its accuracy in the lower neck and supraclavicular region.

Methods

Treatment and Monitoring Setup

Patient data was acquired for OSMS setup for 3 larynx cancer patients (Patients A, B, & D) and 1 tongue cancer patient (Patient C) undergoing volumetric-modulated arc therapy (VMAT) with the Truebeam STx linear accelerator system (Varian, Palo Alto, California) at Juravinski Cancer Centre with either 20 or 30 fractions (200-255 cGy/fraction) beginning in October 2023. The inclusion criteria were: 1) diagnosis of larynx or tongue malignancies; 2) undergoing VMAT radiotherapy. Patients undergoing palliative treatment or patients with difficulties collecting OSMS data were excluded from this study. Patients were informed and asked for consent in their participation in the study, then asked to lower or remove their shirt or gown to expose the supraclavicular region. Patients were positioned using conventional tattoo and laser-based setup and immobilized using a thermoplastic mask covering the head and neck (Aquaplast Corp., Wyckoff, NJ) and the AccuFix™ Head and Neck Device (Qfix, Avondale, PA), as in Figure 1.

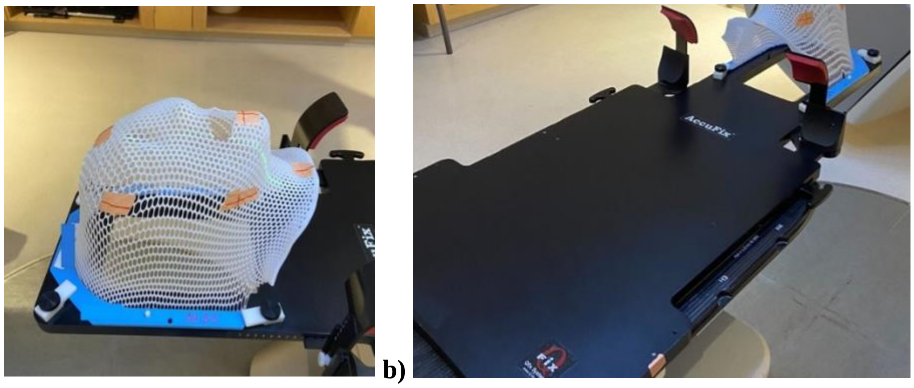

Figure 1. Photograph of the Immobilization Devices Used Throughout the Study. a) Aquaplast RT™ Thermoplastic Mask (Qfix®) - a heat-moldable mask designed for precise immobilization of the head, neck, and shoulders; b) AccuFix™ Cantilever Shoulder Depression System (Qfix®) - carbon fiber-based immobilization device with an adjustable Shoulder-Loc™ system, allowing for optimal shoulder positioning.

Optical Surface Monitoring

Data was exported from the ARIA Oncology Information System (Varian, Palo Alto, California) to computers integrated with the AlignRT's OSMS system (VisionRT, London, UK), consisting of 3 cameras and projectors which measure real-time body surface movement information in 3 cardinal translations and 3 axis rotations. AlignRT matches the current position to the reference position, which can be a surface imported from DICOM or captured using AlignRT, halting the radiation beam when it detects that patient motion has exceeded a certain threshold. This is achieved by projecting a speckle pattern upon the user-defined ROI and calculating the translations and rotations necessary to match the surfaces through a preset rigid body registration algorithm, a method for registering the distance between different images of the same object [20]. The output consists of log files containing Real-Time Deltas (RTDs) displaying the delta shifts in a vertical or AP shift, a longitudinal or SI shift, and a lateral or left-right (LR) shift, as well as rotations about the treatment isocenter for pitch, roll, and yaw. These parameters (as well as various other parameters such as total translation, amplitude, beam state, and root mean squared) are recorded each time a shift is detected, thus having varying time intervals of about 7 seconds. At our institution, the threshold of patient motion for clinical treatment is set to 3.0mm and 3.0° for intrafractional motion monitoring. However, for the purpose of measuring interfractional motion, reference positions were not captured at the beginning of treatment, rather movement was monitored with respect to the DICOM planning CT. This requires a larger range of motion to be measured, thus threshold ranges were increased to a maximum of 9.9mm and 9.9º for translational deviations and rotational deviations, respectively, while the beam hold timer was increased to 5 seconds. Automatic beam hold gating was not utilized. Previous studies have suggested that the ROI should remain stable, avoiding the axillary and lymph drainage regions, and maintaining a sufficient gap between the patient's mask edge and the ROI [21,22]. Additionally, smaller ROIs are found to be more accurate for tumor tracking, whereas larger ROIs are preferable for monitoring positional deviations [21-24]. Thus, an area just below the supraclavicular region illustrated in Figure 2, highlighted in white, was tracked using AlignRT during patient setup and treatment.

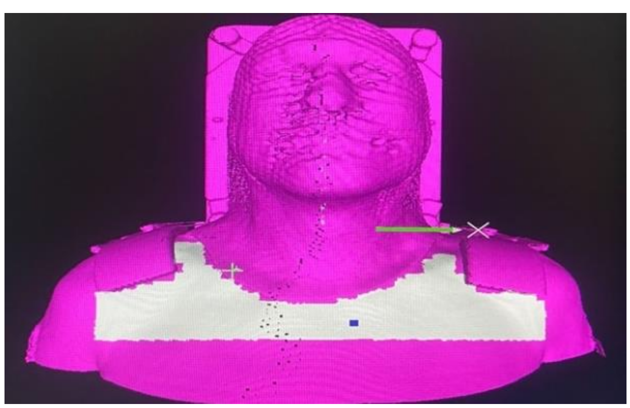

Figure 2. Screen Capture of a 3D Render of a Patient's Body in Purple on Varian Eclipse™ Treatment Planning System (Version 5.0.1749). The ROI for AlignRT tracking was mapped to be the white portion.

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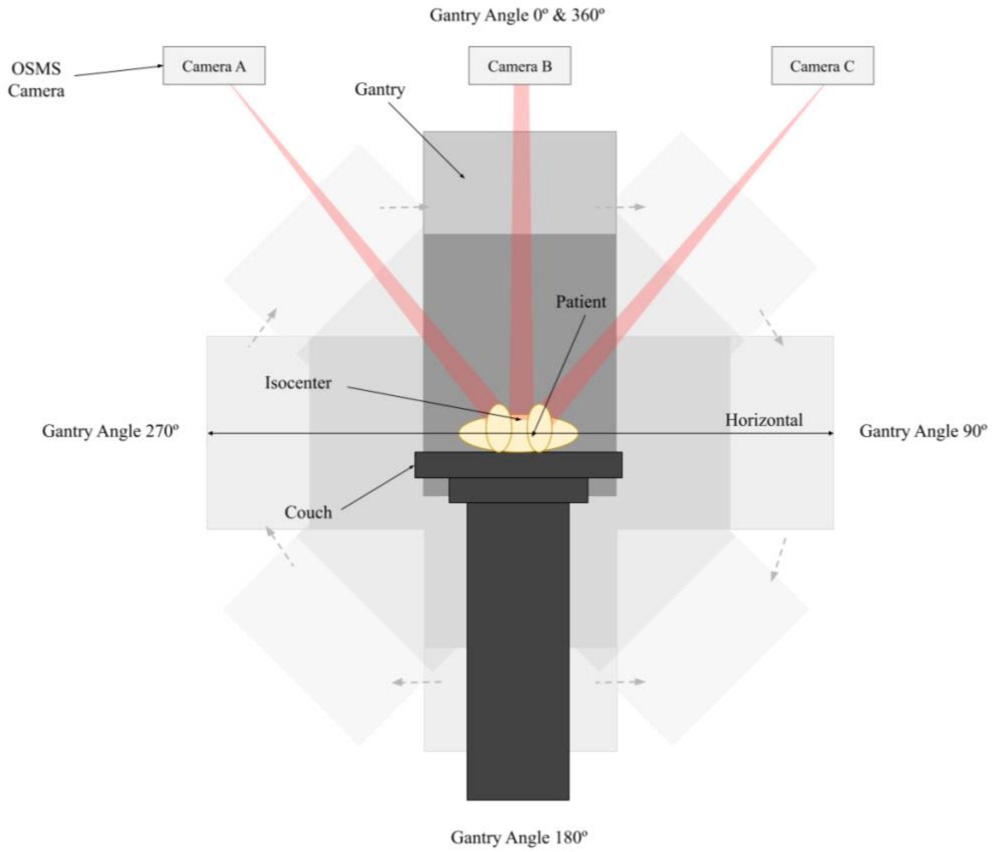

Figure 3. Schematic Diagram of Gantry Angles and OSMS Camera Positioning during VMAT. The optical surface monitoring system incorporates three cameras designated as Cameras A, B, and C. Each camera is mounted to the ceiling. Camera B is offset from the plane of the image towards the viewer. The gantry cannot rotate beyond 180º from the 0º or 360º position. Thus, its movement is as follows: 0º → 90º → 180º → 90º → 0º → 270º → 180º → 270º → 360º. This figure was created using Google Drawings.

AlignRT was used for the duration of the treatment, then the reported log files were exported in the form of .txt files. This raw data was then exported to a .csv file for statistical analyses and graphing in R. At our institution, gantry angles above the horizontal of clockwise and counter-clockwise between 0º and 90º, as well as clockwise and counter-clockwise between 270º and 360º blocked optical surface cameras A, B, and C, as depicted in Figure 3, where the grey box designated the gantry intermittently blocks the red light projected by the cameras. This was determined through patient treatment data in ARIA. Data falling under these angles were skewed or appeared as "N/A" (Appendix 1), and thus were removed. Intrafractional data was gathered by averaging the initial 10 points of OSMS data while the treatment beam was active, then subtracting the following points by that value to determine the positional variance from the start position during treatment. This allows us to ensure each patient's breathing cycle is filtered out. For interfractional data, the mean of the initial 10 points of OSMS data where the treatment beam was inactive was calculated.

CT Image Registration

Planning CT scans were acquired using the SOMATOM Definition AS system (Siemens Healthineers, Erlangen, Germany). Prior to each patient's treatment fraction, kVCBCT were performed using the Truebeam STx. During treatment, kVCBCT and planning CT scans were registered by radiation therapists to match mid-neck anatomy, surrounding the target volume. If a re-CBCT was acquired that treatment fraction, the second CBCT was used. Calculation of positioning using this method will be denoted as target volume-based image matching (TV-IM). To assess variability in shoulder position, automatic kV image rigid body registration was performed on the same image sets using Eclipse, focusing on mid-clavicle alignment under an intensity range of 200 to 1700 Hounsfield units (HU) to focus on bony anatomy, as pictured with the red box in each view in Figure 4. Manual corrections were employed if automated alignment was visually unsatisfactory. Calculation of positioning using this method will be denoted as clavicle-based image matching (C-IM).

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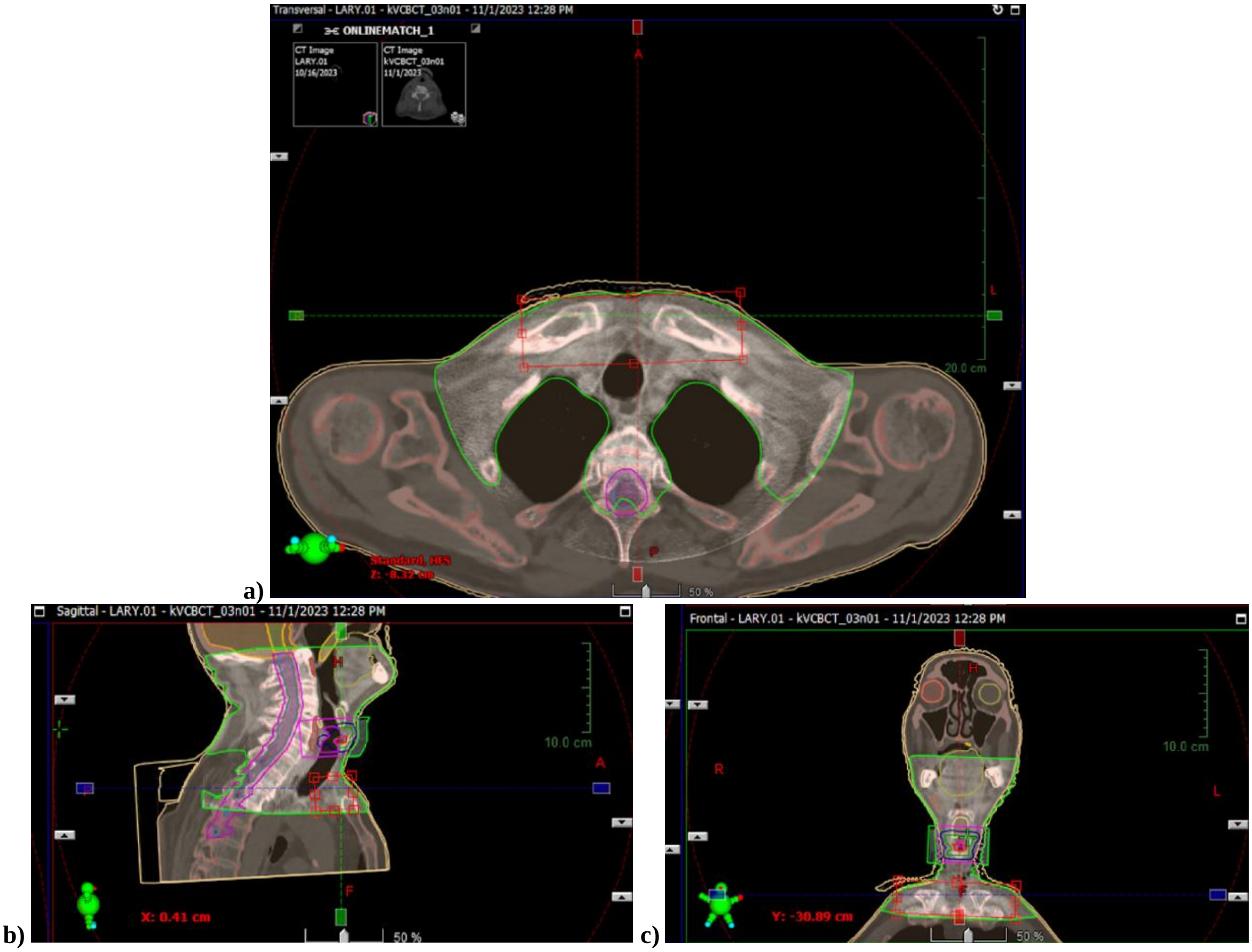

Figure 4. Screen Capture of Clavicle-Based Image Registration (C-IM) Executed in Varian Eclipse™ Treatment Planning System (Version 5.0.1749). Bony anatomy is aligned within the volume of interest (VOI) designated by the red box. The different views are designated as a) transversal, b) sagittal, and c) frontal. The variation in VOI size and shape across views reflects the orientation and dimensions of the clavicle in each imaging plane, ensuring accurate bony alignment from multiple perspectives.

Results

The AlignRT datasets monitoring shifts during radiation treatment for each patient are detailed in Appendix 2. Histogram plots in Appendix 3 reveal that the data are not consistently normally distributed across translational or rotational shifts. The data were organized into clusters based on gantry angle positions during treatment arcs. Cluster 1 encompasses gantry movement from 180º to 270º, while Cluster 2 includes movements from 90º to 180º and from 270º to 180º. These clusters correlate with specific time frames, with separation occurring when the gantry is positioned above the horizontal, obstructing camera views (Figure 3). Cluster analyses in Appendix 4 indicate that organizing data by date is effective, as shifts across clusters remain similar.

Intrafractional Motion

Intrafraction motion measurements, shown in Table 1 and Table 2, compare initial treatment positions with AlignRT data. Most motion in the AP, SI, and LR directions stay within a 5mm margin. The mean percentages of data points exceeding 5mm during treatment were 0.01% (AP), 1.92% (SI), and 1.77% (LR). Notably, shifts over 3mm were more common in the SI (11.05%) and LR (7.23%) directions. Pitch, roll, and yaw rotations typically remained within 3º, with the highest intrafraction rotations seen in pitch (8.86%) and yaw (6.63%) exceeding 1º.

Table 1. Percentages of Translational Shifts Out of All Treatment Fractions Exceeding 3mm and 5mm for Each Patient

	AP (mm)		SI (mm)		LR (mm)	
	> 3mm	> 5mm	> 3mm	> 5mm	> 3mm	> 5mm
A	0.706	0	32.745	7.502	5.649	2.736
B	1.656	0.040	0.767	0	13.772	3.635
C	1.611	0	10.274	0.196	4.990	0.294
D	0	0	0.403	0	4.497	0.403

Notes: Shifts are measured relative to the position at the beginning of treatment, following kVCBCT and delta couch shifts. Delta couch shifts refer to the adjustments made to the treatment couch's position based on kVCBCT image feedback to align the patient's isocenter with the planned treatment position. Shifts analyzed included the AP, SI, and LR directions. Each data point refers to a detection of movement by AlignRT data, recorded about every 7 seconds during an active treatment fraction. Data is sampled exclusively from when the gantry is at or below the horizontal (as depicted in Figure 3).

Table 2. Percentages of Rotational Shifts Out of All Treatment Fractions Exceeding 1º and 3º for Each Patient

	Pitch (º)		Roll (º)		Yaw (º)	
	>1º	>3º	>1º	>3º	>1º	>3º
A	2.118	0	0.530	0	4.678	0.618
B	16.922	0.121	5.614	0.081	13.651	1.575
C	7.926	0	0.196	0	5.186	0
D	8.456	0	3.020	0	3.020	0

Notes: Shifts are measured relative to the position at the beginning of treatment, following kVCBCT and delta couch shifts. Shifts analyzed included pitch, roll, and yaw rotations measured about the treatment isocenter. Each data point refers to a detection of movement by AlignRT data, recorded about every 7 seconds during an active treatment fraction. Data is sampled exclusively from when the gantry is at or below the horizontal (as depicted in Figure 3).

Interfractional Motion

Differences between TV-IM and C-IM in the AP, SI, and LR directions, along with pitch, roll, and yaw rotations, are illustrated in Figure 5 and Figure 6. The middle 50% of fractions remained within +/- 3mm for most patients, although Patient C exhibited larger offsets, particularly in the LR direction as shown in Figure 5c) (over 5mm in 37.04% of fractions). Rotational discrepancies also showed greater variation for Patient C.

AlignRT & Image Registration Consistency

Comparative analyses of C-IM and AlignRT data in AP, SI, and LR directions, as well as pitch, roll, and yaw rotations, are presented in Figure 7 and Figure 8. The middle 50% of fractions showed clavicle positioning offsets ranging from +8mm to -5mm, with LR and SI variations being slightly larger than in the AP direction. The SI direction demonstrated the least accuracy. Rotational discrepancies ranged from +/- 4º, with the largest variations noted in roll and yaw across all patients and fractions.

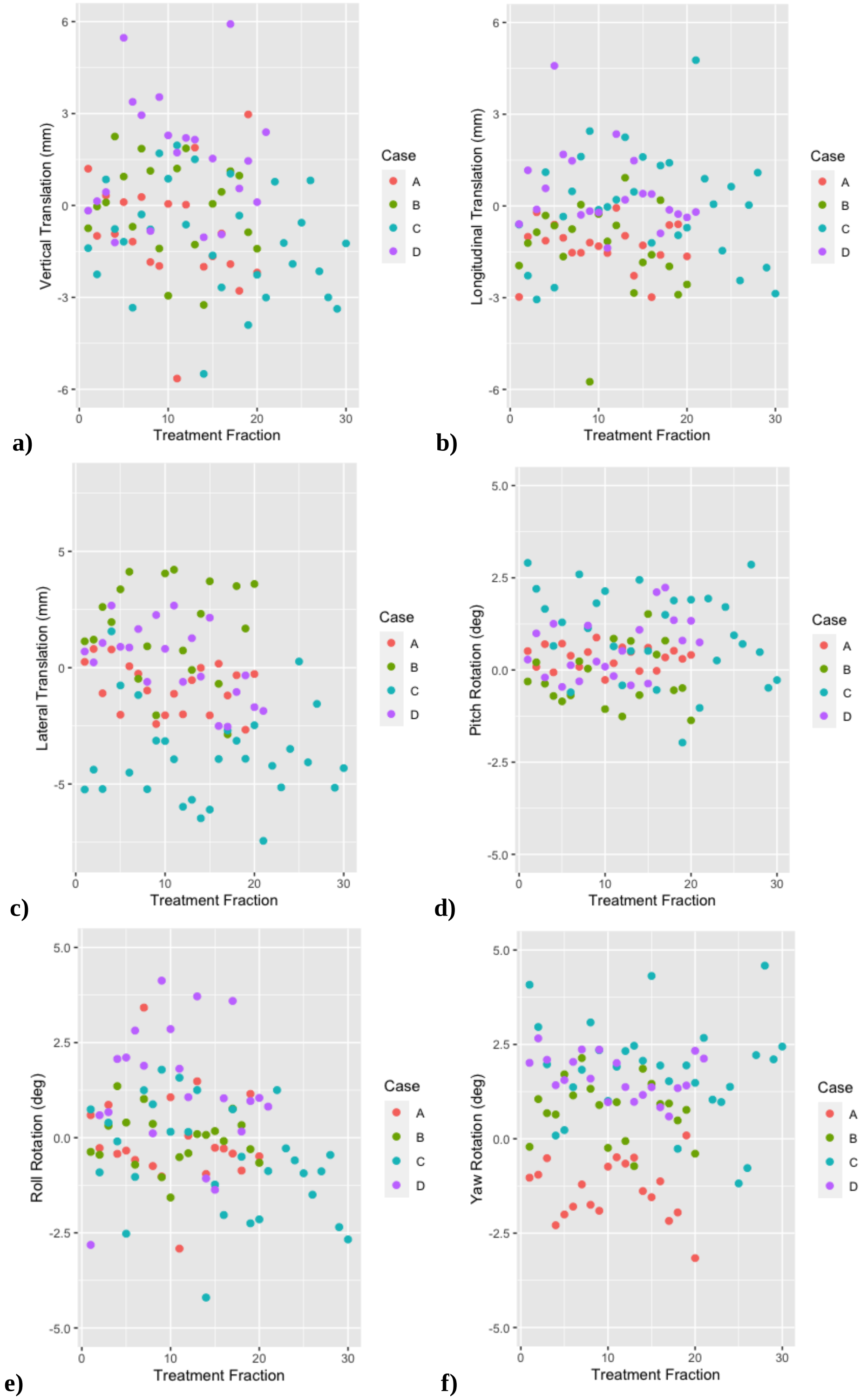

Figure 5. Difference in Patient Clavicle Positioning Across Treatment Fractions Between TV-IM and C-IM Datasets. Each patient is exemplified by a different case and colour. Each point represents the discrepancy between the intended clavicle position and the observed clavicle position for a specific treatment fraction. a) Difference in vertical (AP) translations across fractions; b) Difference in longitudinal (SI) translations across fractions; c) Difference in lateral (LR) translations across fractions; d) Difference in pitch across fractions; e) Difference in roll across fractions; f) Difference in yaw across fractions. This figure was created using R.

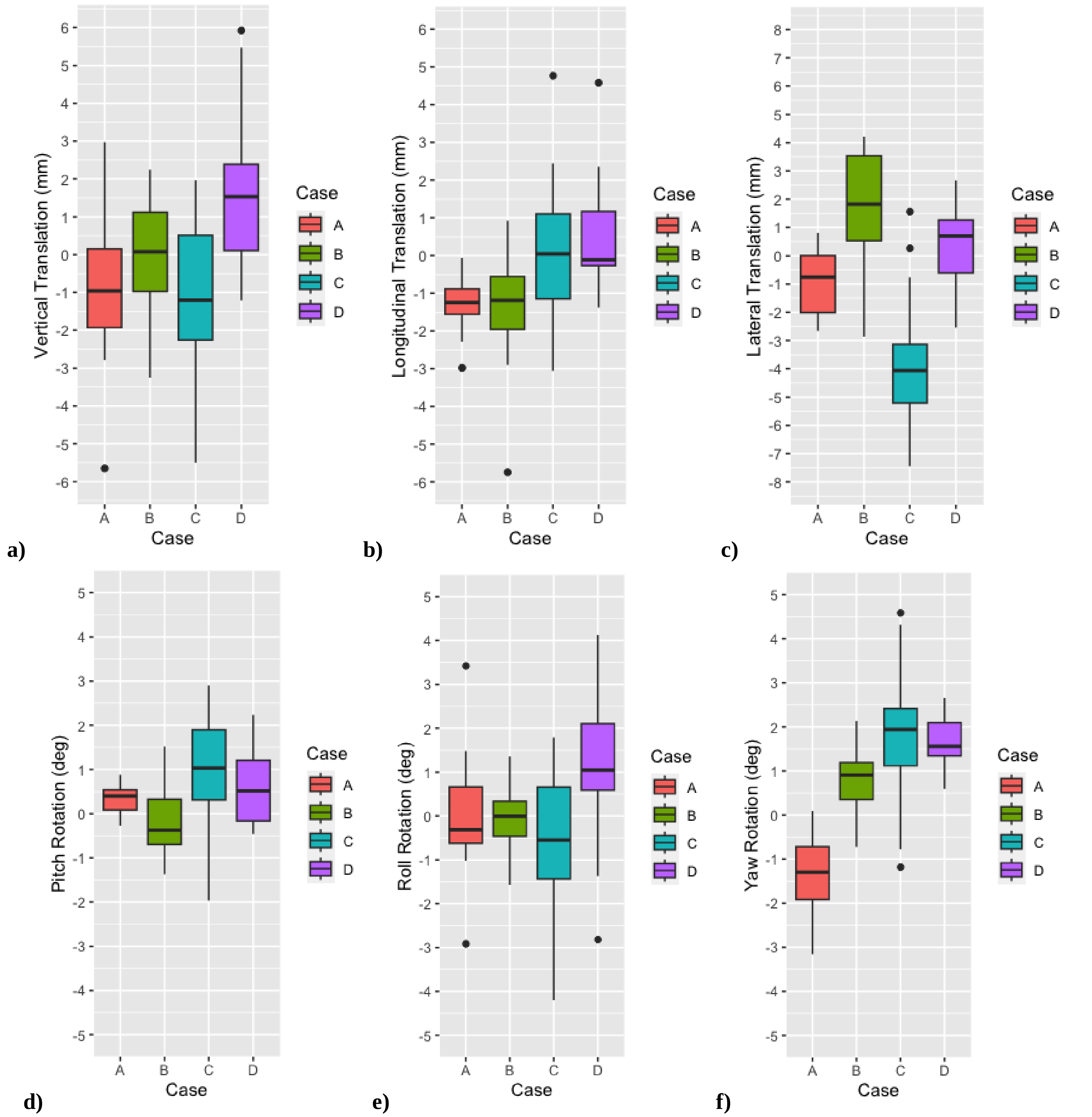

Figure 6. Translational and Rotational Differences in Patient Clavicle Positioning Between TV-IM and C-IM Data. Each patient is exemplified by a different case and colour. Each point represents the discrepancy between the intended clavicle position and the observed clavicle position for a specific treatment fraction. a) Difference in vertical (AP) translations across fractions; b) Difference in longitudinal (SI) translations across fractions; c) Difference in lateral (LR) translations across fractions; d) Difference in pitch across fractions; e) Difference in roll across fractions; f) Difference in yaw across fractions. Boxes represent the middle 50% of observations, with a line representing the median value. Outliers are represented by black circles. This figure was created using R.

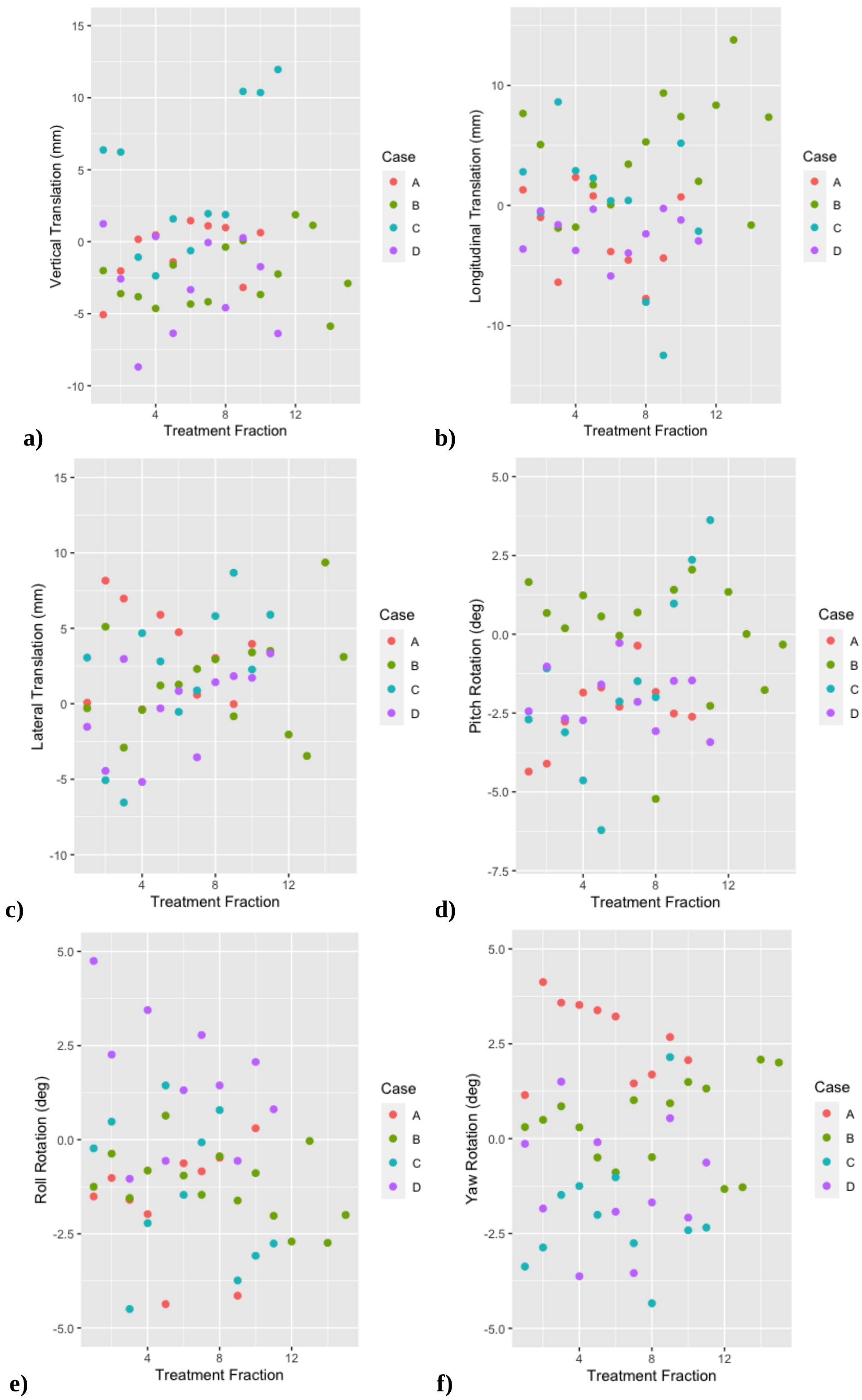

Figure 7. Difference Between Patient Shoulder Positioning Recorded by Image Registration and Recorded by Surface Monitoring Across Treatment Fractions Between C-IM and AlignRT Datasets. Each patient is exemplified by a different case and colour. Each point represents the discrepancy between the observed clavicle position and the AlignRT-recorded clavicle position. a) Difference in vertical translations across fractions; b) Difference in longitudinal translations across fractions; c) Difference in lateral translations across fractions; d) Difference in pitch across fractions; e) Difference in roll across fractions; f) Difference in yaw across fractions. This figure was created using R.

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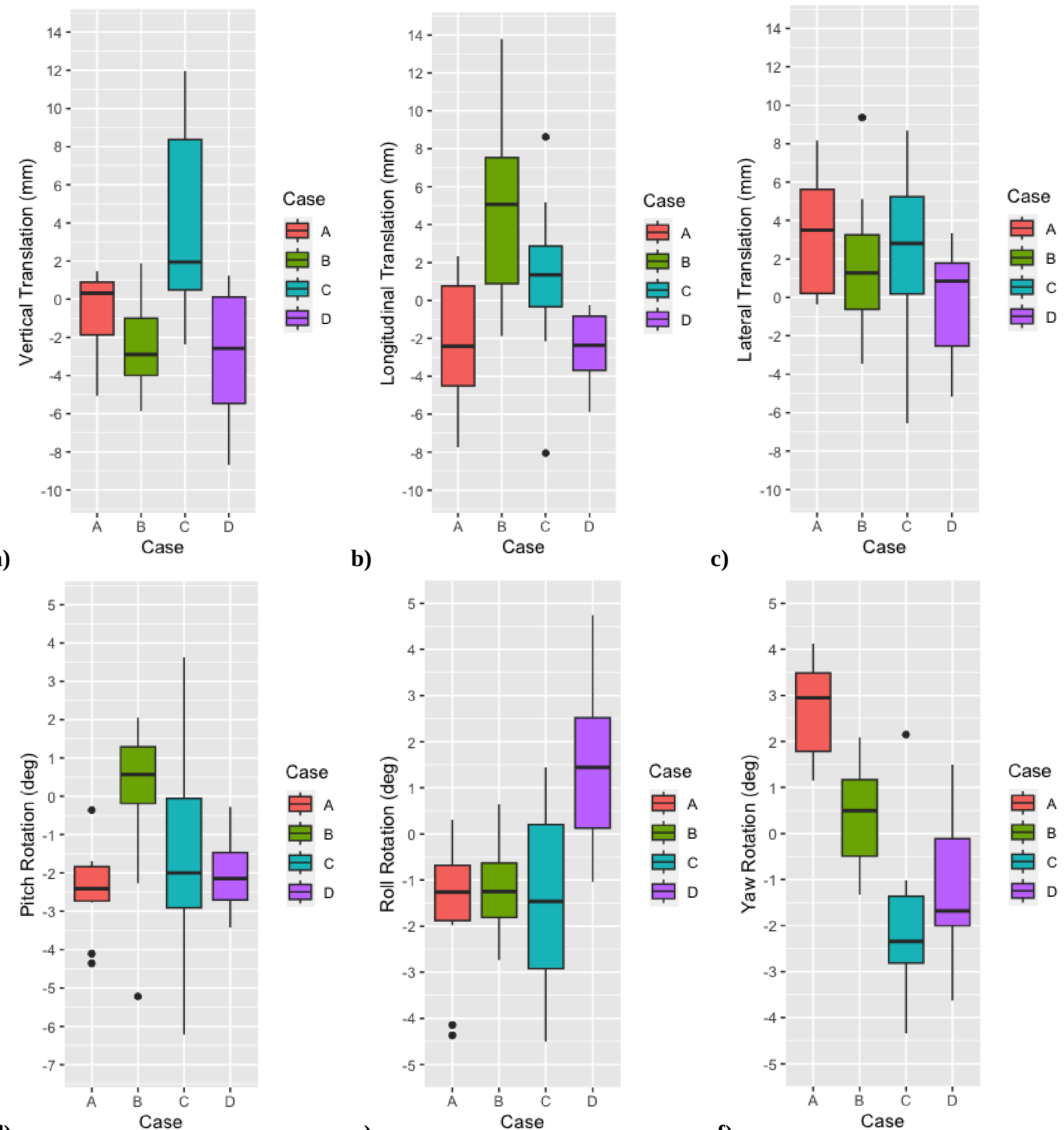

Figure 8. Translational and Rotational Differences in Recorded Patient Clavicle Positioning Between C-IM and AlignRT Datasets. Each patient is exemplified by a different case and colour. Each point represents the discrepancy between the clavicle position as determined by surface monitoring and clavicle position as determined by image registration for a specific treatment fraction. a) Difference in vertical (AP) translations across fractions; b) Difference in longitudinal (SI) translations across fractions; c) Difference in lateral (LR) translations across fractions; d) Difference in pitch across fractions; e) Difference in roll across fractions; f) Difference in yaw across fractions. Boxes represent the middle 50% of observations, with a line representing the median value. Outliers are represented by black circles. This figure was created using R.

Discussion

Our investigation aimed to evaluate shoulder movement using clavicle-based image registration and surface-guided tracking in the supraclavicular region while immobilized with the Accufix™ Head and Neck device. Although literature on the effectiveness of shoulder cantilever depression systems is scarce, many institutions still rely on head and shoulder thermoplastic masks as standard practice [9,10]. Patient-specific data highlighted variability, with Patient A showing minimal deviations, while Patient C demonstrated significantly higher translational and rotational shifts, particularly in the SI and

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yaw axes (Table 1 and Table 2). These patterns suggest anatomical or positioning factors may contribute to these inconsistencies.

Intrafraction motion analysis (Table 1 and Table 2) demonstrated that most shifts in the AP, SI, and LR directions remained within acceptable thresholds, with only 0.01% (AP), 1.92% (SI), and 1.77% (LR) exceeding 5mm. However, deviations greater than 3mm were notably higher in the SI (11.05%) and LR (7.23%) directions. This data emphasizes that while most motion remains within clinical thresholds, the SI and LR directions are more susceptible to intrafraction deviations. This suggests that the immobilization methods keeping the patient in place within a treatment fraction are more sufficient in the AP direction. However, these translational shifts remained under 5mm in 93.58% of cases, while rotational shifts remained under 3º in 99.98% of cases analyzed.

Interfractional analysis using TV-IM and C-IM datasets (Figure 5 and Figure 6) showed that most fractions stayed within ±3mm, however Patient C displayed larger discrepancies, with over 37% of fractions exceeding 5mm in the LR direction. This highlights the need for individualized motion management strategies, with specific attention to patients exhibiting higher variability, such as Patient C. Overall, interfractional movement was found to primarily remain within +/- 3mm, suggesting that positioning and immobilization methods across treatment fractions is sufficient.

However, when assessing the accuracy of AlignRT compared to clavicle-based image registration (Figure 7 and Figure 8), many shifts exceeded expectations. Translational offsets were found to range from +8mm to -5mm, with the SI and LR directions showing greater variability. Rotational discrepancies were most pronounced in roll and yaw, with deviations up to ±4º. This suggests that AlignRT is inaccurate, however this is contradicted by previous validation studies.

In our institution, patient movement during treatment is managed using clinical immobilization devices, primarily thermoplastic masks and shoulder depression systems. Uncertainties arising from technician errors, target motion, and patient setup are typically accounted for by the PTV, which includes a 5mm margin surrounding the target volume. Our results for intrafractional motion align with previous findings that indicated pitch, roll, and yaw shifts are smaller compared to translational shifts, remaining under 5mm for all 41 patients undergoing stereotactic ablative radiation therapy [19]. Nonetheless, many current studies examining intrafractional motion in neck and shoulder regions use methods other than surface-guided techniques, such as live x-ray registration, resulting in limited literature on this specific aspect. Overall, shoulder immobilization appears sufficient during treatment fractions.

Cone Beam Computed Tomography (CBCT) is commonly used to track interfractional movement, guiding patient repositioning before treatment [25]. Prior to each treatment, a kVCBCT scan aligns with the planning CT scan, providing essential guidance for accurate patient positioning. Typically, this alignment matches bony structures surrounding the target volume. Our analysis of interfractional motion focused on shoulder movement, specifically the clavicle area, which mostly stayed within +/- 3mm, with the largest variations in the LR direction. The head and shoulder thermoplastic shell provides a snug fit on the patient's sides, but its lack of constraint in the superior-inferior (SI) direction may contribute to larger shifts [6]. Our study evaluated the shoulder cantilever depression system, which similarly lacks lateral constraints, potentially explaining the observed LR shifts.

The absence of significant shifts exceeding 5mm or 5º in most cases aligns with previous findings on similar immobilization devices. For instance, in a study using helical tomotherapy, setup margins of 5mm were deemed adequate for errors in translational and rotational directions for HNC patients [10]. In another evaluation comparing a Type-S thermoplastic mask to a head-only mask with a shoulder depression system, no significant differences were found in immobilization effectiveness [16]. However, we observed substantial variations in Case C, the only patient with tongue cancer, due to positional differences arising from a greater distance from the clavicles to the isocenter and variations in therapist techniques.

This study explores significant intrafractional discrepancies in clavicle positioning by comparing data from conventional image monitoring (C-IM) to surface-guided radiation therapy (SGRT) using AlignRT. We found that discrepancies often exceed PTV margins, challenging previous assertions that AlignRT has submillimeter accuracy in patient setup and positioning [25-28]. Approximately 50% of institutions utilize SGRT clinically, but challenges remain, particularly concerning free breathing and the selection of regions of interest (ROI) [17].

Free breathing during treatment should not have significantly impacted surface monitoring discrepancies, as we calculated the mean of the first 10 points before treatment. Previous studies suggest that respiration-induced uncertainties have minimal effect on larger setup uncertainties [29]. Although ROI size and location are critical for AlignRT accuracy, there is little evidence that our ROI's shape and size were ineffective. Our ROI was slightly larger than typical for head and neck cancer patients, yet smaller than those used for pelvis or breast radiation therapy [21]. While larger ROIs can result in slower monitoring rates and decreased sensitivity to local anatomical changes, these factors do not impact patient setup tracking [23].

Research indicates that topographically salient features are vital for accurate rotational shift measurements [22]. ROIs with symmetrical or spherical structures, like the breast's surface, face challenges in detecting translational and rotational shifts. The clavicles' symmetry could explain differences in pitch, roll, and yaw shifts between C-IM and AlignRT. Dose distribution can vary significantly from even minor rotations, especially for target volumes far from the isocenter [30]. Flat or planar surfaces have been associated with lateral and longitudinal inaccuracies, which may have contributed to the significant SI and LR discrepancies between our C-IM and AlignRT datasets [23].

An investigation comparing optical surface imaging (OSI) and cone beam computed tomography (CBCT) in head and neck and breast cancer patients found discrepancies due to differences between volumetric and surface imaging [31,32]. Flat images generally contain less information than volumetric images, potentially resulting in lower-than-expected shifts, as observed in most of our SI, AP, pitch, roll, and yaw shifts. Furthermore, the complexity of the head and neck area introduces an average displacement error of 2-3mm after initial setup [33]. A study by Covington et al. showed that larger-than-expected rotational target deviations (RTDs) increased with the distance of the isocenter from the reference surface [34]. These findings suggest the need for regular calibration and the combined use of imaging techniques to improve setup accuracy.

This study is limited by a small sample size of only four patients, resulting from initial data collection difficulties with AlignRT and the inability to include patients who have completed treatment. Additionally, the inclusion of a patient with a non-larynx malignancy and a different isocenter location, as well as treatment administered by a different team of radiation therapists, introduces inter-patient uncertainties that limit both internal and external validity. Almost 50% of the intrafractional motion data points were excluded because AlignRT cameras at times lost track of our ROI due to gantry shielding, leading to skewed information, as explained in the Methods section. Literature indicates that the ROI should reflect the position of surrounding equipment [23], but this is not always feasible. Some studies have opted to exclude skewed data entirely [34,35].

The surface geometry of our ROI also posed challenges in validating interfractional data, primarily due to the planar and symmetrical nature of the clavicle surface. While TV-IM was conducted by experienced planners, C-IM relied on an undergraduate student, potentially introducing uncertainties. Furthermore, our assessment of shoulder and body positioning below the neck was limited by the cone beam CT's range, constraining our analysis of interfractional and intrafractional motion.

Conclusions

Currently, the data obtained from our study suggests that there is some shoulder movement based on the clavicle positioning relative to target volume area immobilization. Both intrafractional and interfractional movement seems to remain within the PTV margins of our institution, with a few outliers. Immobilization of the shoulders has demonstrated adequate accuracy using a shoulder cantilever depression system for larynx cancer patients undergoing VMAT. Alternatively, our observations of the accuracy of AlignRT in tracking the supraclavicular region seems to be much lower than what the literature suggests. Utilizing AlignRT for patient setup in our study was not feasible for reproducing patient shoulder positioning due to our ROI limitations, thus parameters influencing surface-guided systems should be evaluated carefully in future studies. Future research should aim to optimize ROI parameters for surface-guided systems like AlignRT to improve tracking accuracy in the supraclavicular region. A larger sample size and a more diverse patient cohort would also enhance the external validity of our findings. Comparative studies between AlignRT and other surface-guided systems could provide further insight into system-specific limitations and strengths. These refinements could contribute to further developing shoulder immobilization and positioning in larynx cancer VMAT treatments, ensuring both precision and reproducibility across different clinical settings.

List of Abbreviations

AP: anterior-posterior
CBCT: cone beam computed tomography
C-IM: clavicle-based image matching
CT: computed tomography
HNC: head and neck cancer
KVCBCT: kilovolt cone beam computed tomography
LR: left-right
OSMS: optical surface monitoring system
PTV: planning target volume
ROI: region of interest
SI: superior-inferior
TV-IM: target volume-based image matching
VMAT: volumetric modulated arc therapy

Conflicts of Interest

The authors declare that they have no conflict of interests.

Ethics Approval and/or Patient Consent

This study did not require ethics approval, however patient consent was obtained prior to each radiation therapy session.

Authors' Contributions

SC: made substantial contributions to the design of the study, the collection of data as well as interpretation and analysis of the data, drafted the manuscript, and gave final approval of the version to be published.
OO: made substantial contributions to the design of the study as well as the interpretation and analysis of the data, revised the manuscript critically, and gave final approval of the version to be published.

TV: contributed to study design and planning, made substantial contributions to the collection and analysis of data, and gave final approval of the version to be published.
TC: contributed to study design and planning, made substantial contributions to the collection and analysis of data, and gave final approval of the version to be published.

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