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Evaluation of the Interchangeability of Cone Beam Computed Tomography and Catalyst for Patient Positioning in Radiotherapy for Head and Neck Cancer Patients

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Abstract
Background: This study aims to evaluate the interchangeability between cone beam computed tomography (CBCT) and the optical surface scanning system (Catalyst) for daily positioning during radiation therapy in head and neck cancer patients.
Method: This study was designed as a prospective observational descriptive study divided into two parts. The first part involved a phantom study using the computerized imaging reference systems (CIRS) child atom phantom. It aimed to detect deviations in patient position across six degrees of freedom (lateral, longitudinal, vertical, rotation, roll, and pitch) using the optical light scanner and Catalyst and compare them with deviations detected by CBCT in the same treatment sessions. The second part included 252 sessions, during which 30 head and neck cancer patients were treated at Children Cancer Hospital 57357, Egypt, using both Catalyst and CBCT for setup treatment positioning.
Results: The differences between CBCT and Catalyst in all six degrees of deviation were not statistically significant (lateral (P = 0.175), longitudinal (P = 0.296), vertical (P = 0.110), rotation (P = 0.936), roll (P = 0.527), and pitch (P = 0.270)).
Conclusion: The optical light scanner system Catalyst is comparable to CBCT. Surface scanning (Catalyst) has proven reliable and feasible for daily patient positioning, with the advantage of avoiding daily exposure to additional radiation.
***Keywords**:* Radiotherapy, Image-Guided, Cone-beam computed tomography, Catalyst, Head and neck neoplasms

Introduction

Image-guided radiation therapy (IGRT) uses various imaging modalities to improve the precision and accuracy of radiation treatment delivery by correcting potential patient position setup errors. One of the key obstacles in the everyday clinical activities of radiation therapy is the reproducibility of patient setup and organ motion management.[1]

Ionizing radiation machines, such as linear accelerators (for X-ray or photon) or cyclotron/synchrotrons (for proton), are equipped with unique imaging technology (X-ray portal image, computed tomography (CT), 3D body surface mapping, magnetic resonance imaging (MRI), and ultrasound (US) that allow the therapist to image the tumor immediately before or even during the time radiation is delivered.[2,3]

These images are compared to the reference images taken during the simulation.

Technological advancements, such as the advent of cone beam CT (CBCT), have greatly enhanced the precision of tumor dosage delivery and reduced uncertainty.[4,5,6] CBCT-based X-ray technology enables the visualization of internal anatomy with its ability for penetration. The increased frequency of CBCT imaging increases the quantity of radiation dose delivered to patients, increasing the possibility of secondary cancers.

Surface-based systems also allow for continuous, touch-free optical surface scanning of the patient's exterior surfaces, a useful tool for correcting patient position without exposing the patient to further radiation. Optical surface positioning technologies that have recently been created have been brought into clinical practice.[7,8,9]

The Catalyst high-definition optical surface scanner comprises a ceiling-mounted scanning unit and the c4D software. The scanners in the linear accelerator room allow for continuous surface detection. The instrument emits 405 nm (blue) visible light during the scan, and integrated charge-coupled device cameras collect re-projections. The comparison of the surface scan with an initially acquired reference scan is based on photogrammetry principles explained by the fundamental principle used in photogrammetry: triangulation. By taking photographs from at least two different locations, so-called 'lines of sight' can be developed from each camera to points on the object, carried out using a non-rigid iterative nearest point technique in 6 degrees of freedom (refers to the six mechanical degrees of freedom of movement of a rigid body in three-dimensional space for patient body lateral, longitudinal, vertical, rotation, roll and pitch).[10,11]

Additionally, the system includes integrated light-emitting diode (LED) projectors for projecting positional deviations onto the patient's surface to aid in patient positioning. For different deviations, different colored light (green: 528 nm, red: 624 nm) is used to visualize the reference position on the patient's surface.[12,13] Catalyst scanning system based on optically visible light without any additional radiation exposure for patient positioning with visual user assistance in identification of positioning accurately with inter-fractional movements control and automated respiratory gating.[14,15] The purpose of the present study is to evaluate the usage of Catalyst versus CBCT in image-guided radiation sessions for head and neck cancer patients to decrease the total radiation exposure dose received during the treatment course.

Materials and Methods

This study was designed as a prospective observational descriptive research endeavor, encompassing 30 head and neck cancer patients who received treatment at the Children's Cancer Hospital 57357 in Egypt. The study was conducted from June 2020 to November 2020, following approval by the SMAC Committee at 57357 Hospital. All study participants' parents provided written informed consent. Before commencing the study, approval was obtained from the Research Ethics Committee of the Medical Research Institute (Ethics code: IORG0008812) at Alexandria University, Egypt. Our investigation relied on specialized measurement equipment and irradiation facilities, including CT (Somatom, Siemens Healthcare, Germany), MRI (Megatom, Siemens Healthcare, Germany), Treatment Planning System (TPS) (Monaco, Elekta, Sweden), Thermoplastic Mask (Civco, US), Linear Accelerator (Elekta, Versa HD, Sweden), X-ray Volume Imaging (XVI CBCT) (Elekta, Sweden), and Optical Light Scanning System Catalyst (C-RAD, Uppsala, Sweden).

The CT simulation was performed on the initial day of the patients' presentation at the radiotherapy department. A suitable fixation thermoplastic mask with reference marks was meticulously delineated on it. Subsequently, the patients were immobilized in the supine position atop a solid, flat carbon fiber couch at the CT site. An appropriately sized headrest and thermoplastic mask were employed to ensure optimal patient comfort and stability. The headrest was positioned beneath the patient's head, while the mask was prepped in a water bath at a high temperature of 65°C to become flexible and conform to the patient's facial contours. It was then securely affixed to the couch. An index was created and attached to each mask, containing essential patient data and the most comfortable headrest size. These components, the headrest, and mask, played a pivotal role in guaranteeing the reproducibility of patient fixation, thereby minimizing setup errors and facilitating initial target localization. Patients were consistently positioned throughout treatment using the same headrest, mask markers, and immobilization device.

In this study, a CT scanner can acquire multiple images or slices during a single rotation of the X-ray beam around the patient. This advanced CT technology enabled the generation of a three-dimensional image (3D), which was subsequently integrated into the Monaco planning system for contouring and treatment planning purposes.

Phantom study

In the present study, a Phantom was utilized to assess the level of agreement regarding the directions and quantity of deviations between the CBCTs and Catalyst scans. This was achieved by positioning the phantom on the treatment room table couch and utilizing fixed lasers and skin marks to align it with the isocenter.

CBCT imaging was employed to verify the accurate placement of the phantom. The reference surface was captured using the Catalyst system and camera settings, with tolerance adjustments made accordingly.

To ensure the Catalyst and CBCT systems aligned with the same deviation parameters and direction corrections, the treatment couch was manually displaced at intentionally induced 1, 2, and 3 cm deviations in positive and negative directions relative to the isocenter. The results of these deviations are presented in table 1.

Daily workflow

The initial step in our daily workflow involves positioning the patients using a green laser system pre-aligned in the treatment room. Also, reference marks on the mask, previously established during the CT simulation, are used. Following this, the C-RAD Catalyst system is opened, the patient is selected, and the patient's surface is scanned.

Any deviations in setup from the CT simulation (referred to as the reference surface) and the current patient setup in the treatment room surface are meticulously recorded using the C-RAD software. A single camera, securely fixed on the ceiling above the table couch end, aids in this process. Figure 1 provides a visual representation of the setup deviations detected by the Catalyst system.

The subsequent step entails conducting CBCT scan on the patient to estimate their positioning precisely. This involves registering the CBCT scan with the reference CT images and aligning them with the setup deviations recorded earlier (Figure 2).

To ensure the accuracy of our patient positioning, a thorough comparison of the setup errors is needed. The optical light scanner, Catalyst HD, detects the 6 degrees of deviation, including lateral, longitudinal, vertical, rotation, roll, and pitch errors. These deviations are then meticulously compared with the setup errors identified by CBCT, which serves as the gold standard for Imaging-guided radiation therapy.

Statistical analyses

The current study involved a rigorous statistical analysis of data using IBM SPSS software package version 20 (Armonk, NY: IBM Corp). The Kolmogorov-Smirnov test was employed to assess the normal distribution of the data. Quantitative data were summarized using the range (minimum and maximum values), median, mean, and standard deviation.

As determined by the Catalyst technique, patient positioning was subjected to a statistical comparison with positioning data obtained through the CBCT technique, considered the gold standard in imaging-guided radiation therapy. The significance of the results obtained was assessed at a 5% significance level ($P < 0.05$).

Results

The mean ± standard deviation (SD) for deviations in the lateral, longitudinal, and vertical dimensions when comparing CBCT to Catalyst were as follows: -0.01 ± 2.14 cm versus -0.018 ± 2.12 cm, with a *P*-value of 0.662 for lateral; *0*.023 ± 2.14 cm versus 0.021 ± 2.13 cm, with a *P*-value of 0.875 for longitudinal; and 0.043 ± 2.15 cm versus 0.01 ± 2.18 cm, with a *P*-value of 0.120 for vertical.

Statistical analysis of these results revealed non-significant differences between CBCT and Catalyst deviations in lateral, longitudinal, and vertical dimensions ($P > 0.05$).

Clinical study

30 patients, comprising 18 males and 12 females, underwent head and neck cancer treatment. The choice between a closed head mask or a head and neck mask depended on the specific tumor site for each patient. All patients received fractionated external beam radiotherapy, administered using the Elekta Versa HD linear accelerator, with CBCT and Catalyst employed for imaging-guided radiation therapy.

The following results reveal the deviations in patient positioning detected by CBCT and Catalyst during all scheduled radiation treatment sessions, totaling 252 sessions. These deviations were assessed for each of the six degrees individually. In this study, translation degrees (lateral, vertical, and longitudinal) were expressed in centimeters (cm), while the rotational degrees (rotation, roll, and pitch) were expressed in degrees (°).

Comparison between CBCT and Catalyst based on various deviation parameters in a clinical study

Table 2 presents the six different deviation parameters detected by CBCT and Catalyst, while figure 3 illustrates Bland-Altman Plot graphs depicting the agreement between CBCT and Catalyst across these six parameters.

For lateral deviation, CBCT exhibited a range of (-0.16 to 0.33 cm) with a mean ± SD of (0.0 ± 0.096 cm), whereas Catalyst displayed a range of (-0.33 to 0.32 cm) with a mean ± SD of (0.03 ± 0.14 cm). Statistical analysis of these data demonstrated no significant difference between CBCT deviation parameters and Catalyst concerning lateral deviation (P = 0.175).

Regarding vertical deviation, CBCT had a range of (-0.30 to 0.20 cm) with a mean ± SD of (-0.12 ± 0.13 cm), while Catalyst showed a range of (-0.50 to 0.40 cm) with a mean ± SD of (-0.16 ± 0.18 cm). The statistical analysis indicated no significant difference between CBCT and Catalyst concerning vertical deviation (P = 0.110).

For rotation deviation, CBCT exhibited a range of (-2.29° to 1.91°) with a mean ± SD of (-0.23° ± 0.82°), while Catalyst displayed a range of (-2.0° to 1.17°) with a mean ± SD of (-0.25° ± 0.79°). The statistical analysis of rotation deviation demonstrated no significant difference between CBCT and Catalyst (P = 0.936).

In the case of roll deviation, CBCT had a range of (-2.50° to 1.50°) with a mean ± SD of (-0.15° ± 1.10°), while the Catalyst showed a range of (-2.0° to 2.67°) with a mean ± SD of (0.13° ± 1.33°). The statistical analysis of roll deviation revealed no significant difference between CBCT and Catalyst (P = 0.527).

Lastly, in terms of pitch deviation, CBCT exhibited a range of (-1.33° to 1.40°) with a mean ± SD of (0.22° ± 0.66°), while the Catalyst displayed a range of (-1.50° to 2.09°) with a mean ± SD of (0.47° ± 0.91°). The statistical analysis for these data indicated no significant difference between CBCT and Catalyst concerning pitch deviation (P = 0.270).

Discussion

The differences between CBCT and Catalyst in all six degrees of deviation were not significant (lateral (P = 0.175), longitudinal (P = 0.296), vertical (P = 0.110), rotation (P = 0.936), roll (P = 0.527) and pitch (P = 0.270)).

The Catalyst is now utilized to position the patients in several radiation therapy hospitals and clinics. There is restricted proof of its absolute dependability and durability in daily practice.[16]

The current study evaluated and compared the six deviation parameters between CBCT and Catalyst. The statistical analysis of these data did not show significant differences between CBCT and Catalyst in the six deviation parameters (lateral, longitudinal, vertical, rotation, roll, and pitch).

In line with the present study findings, Stanley et al. (2017),[11] concluded that the patient alignment using the catalyst was significantly approaching the alignment carried out by the CBCT. Further, the Catalyst is a trustworthy alternative to traditional positioning using X-ray-based techniques via CT simulation markers on the fixation mask and lasers in the treatment room. They recommended using the optical light scanner Catalyst in daily patient positioning to decrease the total ionizing radiation dose for patients. In the current study, a systematic analysis compared Catalyst imaging to CBCT in the same treatment session to prevent intrafractional patient position uncertainty.

A similar more recent study published by Ma et al. (2018),[13] utilized Catalyst in breast cancer patients for patient positioning during radiation therapy and the deviations were compared with CBCT and found that CBCT and Catalyst did not show any significant difference for all 3 translation deviations where they did not attempt the 3 other rotational deviation. Moreover, Liu et al. (2020),[17] suggested that Optical surface imaging can be applied to positioning breast cancer patients accurately without unnecessary imaging doses.

Carl et al. (2018)[12] found that Catalyst was a reliable and beneficial positioning system for patients in the daily workflow without further radiation exposure. This was in concordance with the present study. A previous report created by Wikström et al. (2014)[14] recommended that the optical light scanning system was an excellent supplement to the CBCT system for accurate setup when no CBCT is deemed necessary for pelvic targets. Furthermore, cropping near the PTV will lead to removing the critical data that may affect the calculation of deviations.

Bekke et al. (2018)[15] contradicts our results; his study concluded that the target position verification cannot be based solely upon surface-based configuration, internal anatomical verification of target position techniques such as kV (CBCT) and MV (Portal images) is essential and required. However, the present study recommendations included the advantage of using the CBCT twice a week (more or less) to ensure that the Catalyst system works well with the same accuracy as the CBCT.

Based on this study, it is recommended that:

- Using an optical light scanner system Catalyst for daily patient positioning instead of CBCT without further ionizing radiation exposure, especially in children patients as included in the current study.
- Upgrading the Catalyst system from one to three camera scanners with open masks for head and neck cancer patients is an excellent choice to enhance the patient's positioning and comfort of the patient.
- CBCT is used periodically to confirm the effectiveness of the optical light scanner system Catalyst in patient positioning.

Some limitations in the current study include the following: The tumor's location is not defined inside the head and neck clinical site and is not related to our results; more investigations are needed to explore the dependency of catalyst imaging on how far the tumor is to the patient surface. Another limitation was the limited number of recruitment patients in the current study.

Conclusion

There is no significant difference between CBCT and Catalyst in all six degrees of deviation in head and neck patient positioning (Lateral, Longitudinal, Vertical, Rotation, Roll, and Pitch). The Catalyst's optical light scanner system is compatible with CBCT, so the Catalyst is reliable and feasible IGRT for daily patient positioning without additional radiation exposure. Further Investigations should include other clinical sites such as chest, abdomen, and pelvic tumors in future work.

Conflict of Interest

None declared.

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Table 1. Comparison between CBCT and Catalyst according to lateral, longitudinal, and vertical degrees in the phantom study.

Lateral	**CBCT**	**Catalyst**
-3 cm	2.96 cm	2.91 cm
-2 cm	2.03 cm	1.96 cm
-1 cm	0.94 cm	0.97 cm
+1 cm	-1.00 cm	-0.96 cm
+2 cm	-1.99 cm	-1.98 cm
+3 cm	-3.00 cm	-3.01 cm
Longitudinal		
-3 cm	2.97 cm	2.95 cm
-2 cm	2.04 cm	2.03 cm
-1 cm	1.01 cm	1.02 cm
+1 cm	-0.96 cm	-0.96 cm
+2 cm	-1.97 cm	-1.93 cm
+3 cm	-2.98 cm	-2.94 cm
Vertical		
-3 cm	3.01 cm	3.05 cm
-2 cm	2.08 cm	2.07 cm
-1 cm	1.05 cm	0.98 cm
+1 cm	-0.95 cm	-0.99 cm
+2 cm	-1.99 cm	-2.07 cm
+3 cm	-2.94 cm	-2.98 cm

CBCT: Cone-beam computed tomography

Table 2. Comparison between CBCT and Catalyst according to six different degrees in the clinical study.

Degree	CBCT	Catalyst	Z	*P*
Lateral				
Min. – Max. Mean ± SD.	-0.16 – 0.33 cm 0.0 ± 0.096	-0.33 – 0.32 cm 0.03 ± 0.141	1.355	0.175
Longitudinal				
Min. – Max. Mean ± SD.	-0.53 – 0.50 cm 0.02 ± 0.25	-0.20 – 0.50 cm 0.06 ± 0.18	1.046	0.296
Vertical				
Min. – Max. Mean ± SD.	-0.30 – 0.20 cm -0.12 ± 0.13	-0.50 – 0.40 cm -0.16 ± 0.18	1.600	0.110
Rotation				
Min. – Max. Mean ± SD.	-2.29° – 1.91° -0.23° ± 0.82	-2.0 °– 1.17° -0.25° ± 0.79	0.080	0.936
Roll				
Min. – Max. Mean ± SD.	-2.50 °– 1.50° -0.15° ± 1.10	-2.0° – 2.67° 0.13° ± 1.33	0.633	0.527
Pitch				
Min. – Max. Mean ± SD.	-1.33° – 1.40° 0.22° ± 0.66	-1.50° – 2.09° 0.47°± 0.91	1.103	0.270

Z: Z-test describes the deviation from the mean in standard deviation units; *P*: *P* value for comparing CBCT and Catalyst. CBCT: Cone-beam computed tomography, Min: Minimum, Max: Maximum, SD: Standard deviation

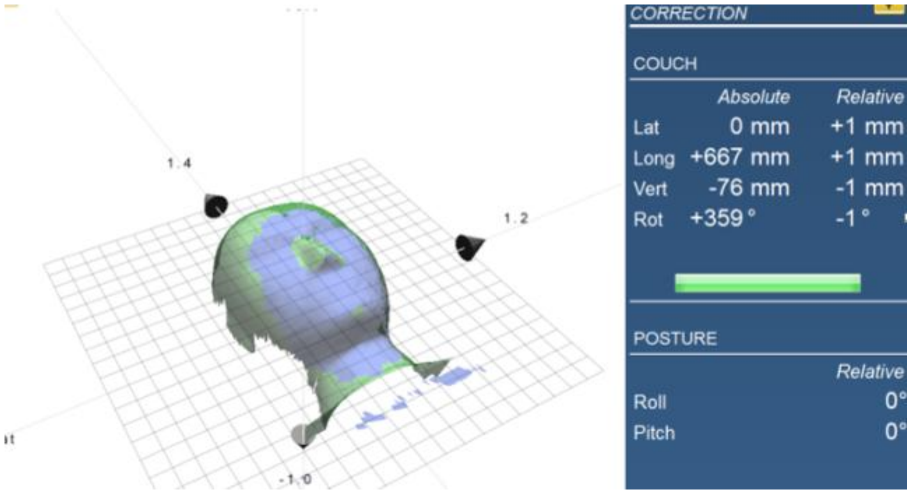

Figure 1. CBCT imaging the patient to estimate the patient's positioning. CBCT scan matching registration was done with the reference CT images, and the setup deviations were recorded.

CBCT: Cone-beam computed tomography, Lat: lateral, Long: longitudinal, Vert: vertical, Rot: Rotation

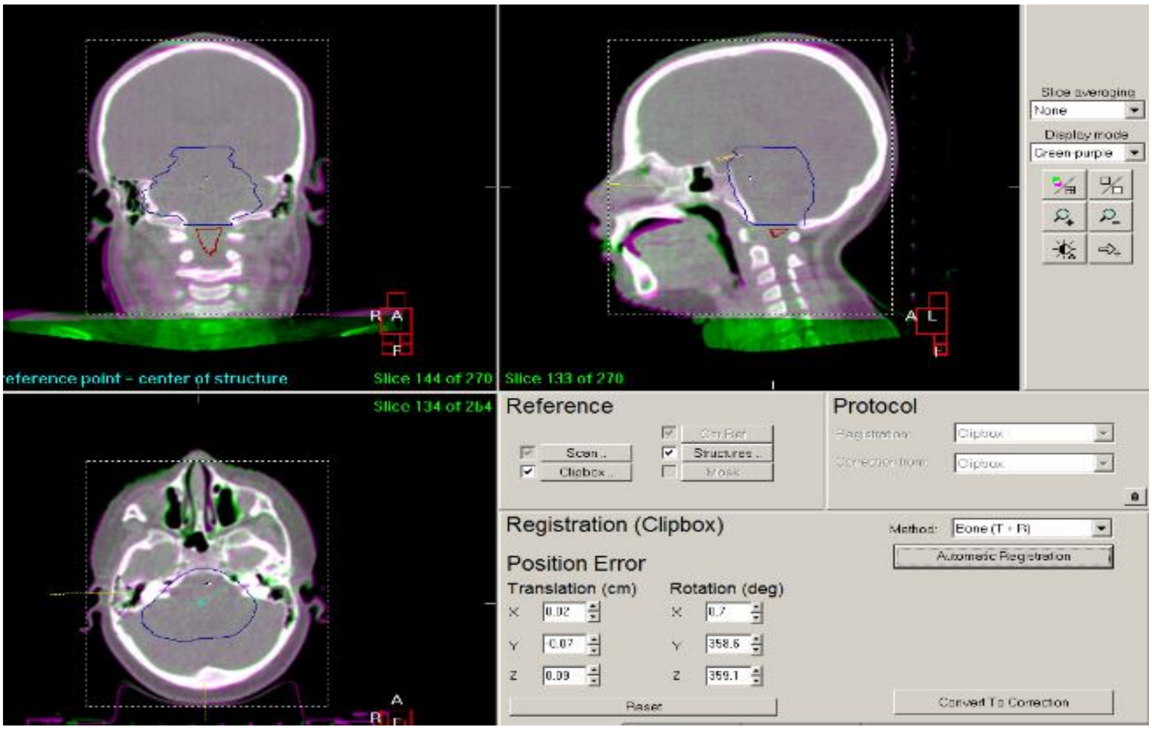

Figure 2. CBCT scan matching registration was done with the reference CT images, and the setup deviations were recorded.

CBCT: Cone-beam computed tomography

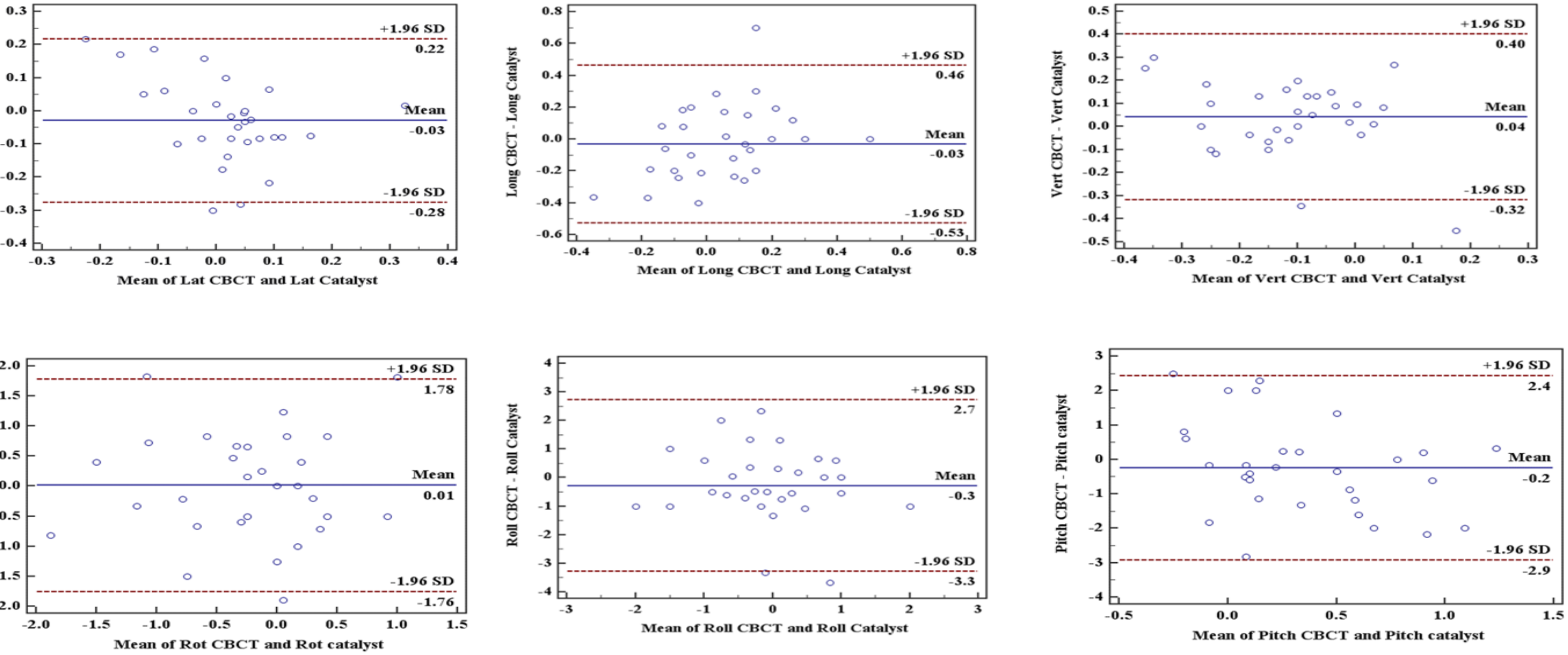

Figure 3. Bland Altman Plot graphs showing Agreement between CBCT and catalyst according to six different degrees.

CBCT: Cone-beam computed tomography; Lat: lateral, Long: longitudinal, Vert: vertical, Rot: Rotation, SD: Standard deviation