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CT Number Stability of Plasticine Bolus Based on HU Measurements in 25-Fraction 6 MV Radiotherapy

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ABSTRACT

This study investigates the Hounsfield Unit (HU) stability of plasticine bolus material during fractionated radiotherapy to evaluate its suitability for clinical application in external beam radiotherapy. A plasticine bolus (10×10 cm², 1 cm thickness) was subjected to 25 fractions of 6 MV photon irradiation using a linear accelerator (LINAC). HU values were measured at baseline and after fractions 5, 10, 15, 20, and 25 using a Canon Aquilion CT-simulator (120 kVp, 300 mAs, 2 mm slice thickness). Dose distribution parameters (minimum, maximum, and mean doses) were calculated using ARIA Treatment Planning System (TPS) at each measurement point. The plasticine bolus demonstrated a baseline HU of 120, increasing to 130 HU (maximum deviation of 10 HU or 8.3%) by fraction 10, with values remaining stable through fraction 25. The peak HU change occurred at fraction 15 (131 HU, representing 9.2% deviation). Corresponding dose variations were minimal: mean dose decreased by 0.11% (from 5035.5 to 5029.8 cGy), minimum dose by 0.43% (from 3751.0 to 3735.0 cGy), and maximum dose by 0.23% (from 5128.5 to 5116.8 cGy). All HU changes remained well below the clinical tolerance threshold of ±20 HU, and dose variations were substantially lower than the 1-2% clinical significance threshold. These findings demonstrate that plasticine bolus maintains adequate HU stability for short-to-medium fractionation protocols (≤25 fractions) when proper quality assurance is implemented, though it exhibited higher HU variability compared to silicone-based alternatives reported in literature.

Keywords: Hounsfield Unit; plasticine bolus; fractionated radiotherapy; dose distribution; treatment planning system; clinical tolerance.

INTRODUCTION

Radiotherapy using a Linear Accelerator (LINAC) has become the primary modality for cancer treatment due to its ability to produce megavoltage (MV) photon beams with high dose precision [1]. The success of this therapy is determined by the accuracy of dose delivery to the tumor through a Treatment Planning System (TPS) in order to minimize exposure to healthy organs (Organs at Risk). To support its effectiveness, a fractionation method is used dividing the total dose into several small sessions which aims to give healthy tissue the opportunity to recover between

treatments, given that healthy cells have a better ability to repair damage than tumor cells [2], [3].

Computed tomography (CT) imaging provides the geometric and density information necessary for accurate dose calculation in radiotherapy treatment planning. The CT number, expressed in Hounsfield Units (HU), quantifies the linear attenuation coefficient of tissue relative to water and serves as the fundamental input for electron density conversion in Treatment Planning Systems (TPS) [4]. The accuracy and consistency of CT number measurements are critical, as these values are converted into Relative Electron Density (RED) through calibration curves, directly affecting dose calculation accuracy [5]. For bolus materials used in fractionated radiotherapy, maintaining stable CT numbers throughout the treatment course is essential to ensure dosimetric consistency and treatment efficacy [6].

Bolus is used in radiotherapy to overcome skin-sparing effects by increasing the surface dose, optimizing dose deposition at shallow depths, and compensating for irregular body contours [7]. In addition to increasing the surface dose, the application of bolus aims to: (1) protect healthy tissue from radiation spread, (2) limit the penetration of rays into the tissue surrounding the tumor, and (3) produce a uniform dose distribution [8], [9]. However, bolus placement must be carefully considered during planning and patient positioning to avoid dosimetric uncertainty due to contour changes [4].

Although commonly used in Indonesia, plasticine has highly flexible properties that cause plastic deformation; the material cannot return to its original shape after being compressed. This dimensional instability risks reducing dose absorption consistency and dose distribution accuracy during the fractionation period [10]. In addition, its physical density is recorded as exceeding the density of skin tissue. However, with careful planning, plasticine remains functional. TPS simulation studies show that a 0.5 cm thick plasticine bolus with 15 MeV electron energy is optimal for cases of fibrosarcoma 2.0 cm deep [7].

The stability of Hounsfield Unit (HU) values in bolus during fractionated radiotherapy is crucial because HU is converted into Relative Electron Density (RED) for dose calculations in TPS. Variations in HU values can shift the HU-RED calibration curve, which can potentially cause dose inaccuracy [6]. Although deviations of approximately ±20 HU in soft tissue generally only cause a 1-2% change in dose [11], [12], longitudinal studies on bolus HU stability are still very limited. This study aims to characterize the baseline HU values of the plastisin bolus and analyze their changes during 25 fractions of 6-MV photon radiotherapy to ensure that these values remain within the clinical tolerance limits (±20 HU).

MATERIALS & METHODS

Study Design

This study employed an experimental quantitative design to evaluate HU value changes in plasticine bolus measured repeatedly during several fractionated radiotherapy sessions.

Bolus Fabrication

A plasticine bolus measuring 10×10 cm² with a thickness of 1 cm was prepared. The bolus was formed homogeneously to ensure consistency across the sample. Plasticine was selected because it is the most commonly used bolus material in various radiotherapy facilities in Indonesia, despite having weaknesses related to shape stability and consistency.

Instrumentation

This study uses several key instruments based on standardization that have been calibrated according to the user manual and tool guide [13]: (1) Canon Multislice HELICAL CT SCANNER LB Aquilion (Product Data No. MPDCT0647EAE) for image acquisition and HU measurement, with scanning parameters maintained constant including tube voltage of 120 kVp,

tube current of 300 mAs, and slice thickness of 2 mm to maintain result consistency; (2) VARIAN Linear Accelerator (LINAC) with 6-MV photon energy to deliver 25 radiation fractions to the plasticine bolus according to clinical protocol; (3) ARIA Treatment Planning System software to calculate dose distribution (min, max, mean) on the target volume with the bolus; and (4) Acrylic phantom used as the base for bolus placement during CT scanning and irradiation.

PROCEDURE

The research procedure was conducted in several stages. Stage 1: Baseline CT Acquisition Baseline CT acquisition of the bolus on an acrylic phantom with constant parameters (120 kVp, 300 mAs, 2 mm slice). Region of Interest (ROI) was placed in the center of the bolus to obtain average HU and standard deviation. CT images were documented for visual characteristic analysis of the material. Stage 2: Radiation Fraction Administration of 6-MV photon radiation fractions up to a total of 25 fractions using LINAC. Each bolus was positioned consistently on the acrylic phantom for each irradiation fraction. Stage 3: Serial HU Measurement, HU re-measurement after fractions 5, 10, 15, 20, and 25 with the same CT protocol. ROI was placed at consistent locations for each measurement. Average HU values and standard deviations were documented at each measurement point. Stage 4: TPS Dose Distribution Simulation For each fraction point, updated HU values were entered into TPS to calculate min dose, max dose, and mean dose. Dose distribution at each measurement interval was compared with baseline.

Data Analysis

Data obtained were analyzed quantitatively with several parameters. HU Calculation: Average HU and standard deviation at each fraction point; percentage HU deviation of each fraction against baseline HU using the formula: % HU Deviation = [(Fraction HU - Baseline HU) / Baseline HU] × 100%. Dose Distribution: Changes in min, max, and mean dose per fraction compared to baseline; percentage dose changes (min, max, mean) and their comparison to the 1-2% tolerance limit. Stability Evaluation: Comparison of maximum HU changes with clinical tolerance limits (±20 HU); comparison of maximum dose changes with clinical thresholds (1-2%); determination of "Pass" or "Fail" status based on tolerance criteria.

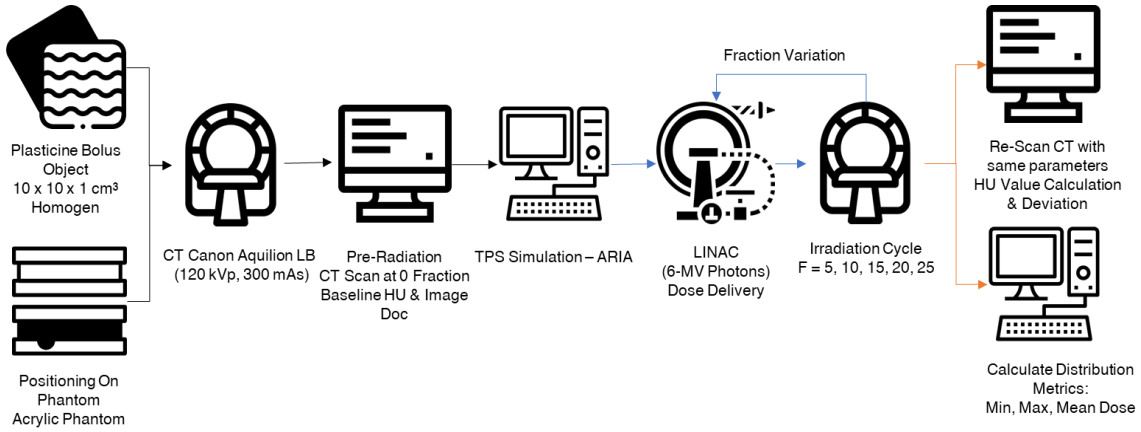

Figure 1. Schematic Illustration of Materials and Methods (Icone designed by Freepik)[22]

RESULT

Baseline Characteristics of Plasticine Bolus

The plasticine bolus showed baseline characteristics that differed significantly from other bolus materials. The baseline HU value measured through CT-Simulator Canon Aquilion with constant parameters of 120 kVp and 300 mAs is presented in Table 1.

Table 1. Baseline Characteristic of Plasticine Bolus

Parameter	Value
Baseline HU	120
Standard Deviation	± 9 HU
Density Category	Between adipose tissue and soft tissue
Visual Elasticity	Low

Table 1 data shows a baseline plastisin bolus value of 120 ± 9 HU, which places it in the density spectrum between adipose tissue and soft tissue. This is consistent with the findings of Sutanto et al. (2019) that plastisin density slightly exceeds normal skin tissue. Visually, the initial CT image shows small areas of hypodensity and hyperdensity, indicating the presence of air pockets or material inhomogeneity, which is confirmed by a fairly high standard deviation value [14].

CT Imaging Analysis

Baseline CT Imaging

The basic imaging process was performed using a Canon Aquilion CT simulator with technical parameters including a tube voltage of 120 kVp, a current strength of 300 mAs, and a slice thickness of 2 mm to evaluate the plasticine bolus material. In each scan result, a region of interest (ROI) measuring several mm² was placed in the center of the bolus to extract the average HU value and standard deviation data.

Visually, the basic CT image representation for the plasticine bolus showed a number of small-scale hypodense and hyperdense areas, indicating the presence of air pockets or material inhomogeneities. This phenomenon was consistent with the high HU standard deviation values recorded for this material.

Post Fraction 25 CT Imaging

Repeat CT scanning at fraction 25 showed an increase in the average bolus value of plasticine to approximately 130 HU. Although no extreme macroscopic deformation was observed, the wide standard deviation and uneven density distribution confirmed an increase in effective density and internal inhomogeneity. This reinforced the indication that plasticine has low microstructural stability during continuous use.

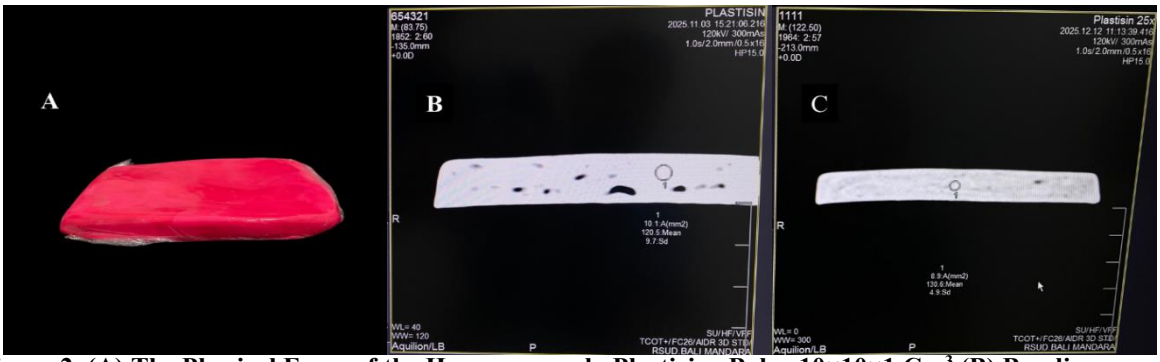

Figure 2. (A) The Physical Form of the Homogeneously Plasticine Bolus 10×10×1 Cm³ (B) Baseline Imaging Results; (C) Image Results After 25 Fractions

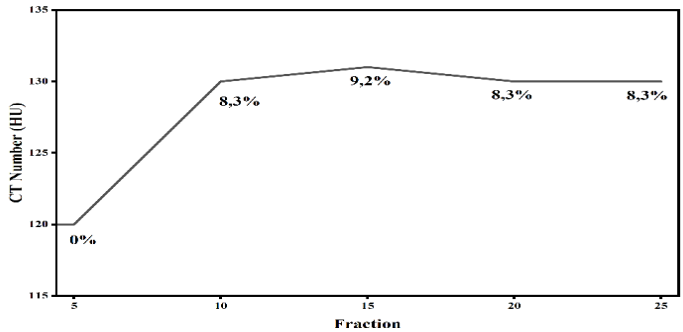

Figure 3. Plasticine Bolus HU Value Changes During 25 Fractions results after 25 fractions

HU Value Changes During Fractionation

HU value measurements were performed periodically at intervals of every 5 fractions up to a total of 25 fractions to evaluate the stability of the plasticine bolus material against repeated radiation exposure. Figure 3, presents the HU value changes of the plasticine bolus at each measurement. To quantitatively evaluate the level of HU value changes, percentage deviation calculations were performed for each measurement point against baseline values. The percentage deviation was calculated using the formula:

$$Deviasi\ (\%) = \frac{HU_{fraksi} - HU_{baseline}}{HU_{baseline}} \times 100$$

From Figure 3, the plasticine bolus showed fairly fluctuating density dynamics. Although stable at 120 HU up to fraction 5, there was a significant increasing trend starting from fraction 10, reaching its peak at 131 HU at fraction 15. By the end of observation (fraction 25), the HU value settled at 130 HU. This cumulative increase of 10 HU or equivalent to 8.3% provides strong indication of reorganization or modification of molecular structure in plasticine as an impact of continuous radiation exposure. Figure 3 data shows a 9.2% increase in plasticine bolus value in fraction 15, indicating significant structural changes due to radiation. This phenomenon is strongly suspected to originate from polymer degradation through chain scission mechanisms or oxidation reactions caused by free radicals. This critical point marks the transition phase before the material reaches a saturated or stable condition.

Impact of HU Value Changes on TPS Dose Distribution

Baseline Dose Distribution

The Hounsfield Unit (HU) value of the CT image is a fundamental input for the TPS to calculate dose distribution through conversion to Relative Electron Density (RED). This HU-RED calibration curve allows the system to account for material heterogeneity in the radiation beam path. Figure 4 presents the TPS-calculated dose distribution for the plasticine bolus at baseline conditions prior to the start of the fractionation process.

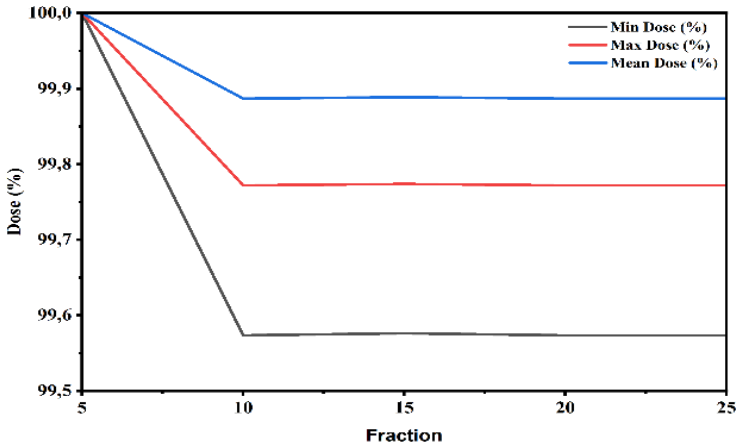

Figure 4. Visualization of Changes in Placticine Bolus Dose Distribution During 25 Fractions in Percents

Dose Distribution Changes During Fractination

Table 2 data shows that the plasticine bolus recorded a minimum dose of 3751.0 cGy and an average of 5035.5 cGy. This value is influenced by the low HU of plasticine (120 HU), which produces a Relative Electron Density (RED) equivalent to low-density soft tissue. As a result, radiation beam attenuation is minimal, so energy transmission to the target depth remains high.

To evaluate the impact of HU fluctuations on dose distribution, simulations were repeated at each interval (fractions 5, 10, 15, 20, and 25) using the latest HU values. Table 2 summarizes the changes in dose distribution resulting from the plastisin bolus due to these parameter updates.

Table 2. Placticine Bolus Dose Distribution Changes During 25 Fractions

Fraction	Min Dose (cGy)	Max Dose (cGy)	Mean Dose (cGy)
Baseline	3751,0	5128,5	5035,5
5	3751,0	5128,5	5035,5
10	3735,0	5116,8	5029,8
15	3735,1	5116,9	5029,9
20	3735,0	5116,8	5029,8
25	3735,0	5116,8	5029,8

Table 2 data shows that an increase in plastisin HU value from 120 to 130 HU has a direct impact on dose reduction in TPS. There was a minimum dose reduction of 0.43% (16.0 cGy), a maximum dose reduction of 0.23% (11.7 cGy), and an average dose reduction of 0.11% (5.7 cGy). Although nominally small, this consistent downward trend proves that an increase in HU value strengthens the attenuation power of plasticine, which in turn reduces the intensity of radiation energy reaching the target volume.

Clinical Tolerance Evaluation

Clinical Tolerance Standard for HU Changes The accuracy of Hounsfield Unit (HU) calibration on CT and the consistency of HU values of bolus material is determining factors for dose precision in TPS. Based on international guidelines (IAEA, AAPM, and ICRU), HU value deviations within a range of ±20 HU for soft tissue categories are considered safe because they only trigger dose fluctuations of less than 1-2% in the target volume.

Research by Zurl et al. (2014) and Davis et al. (2017) confirmed that HU variations within these limits do not cause clinically significant dosimetric errors. This is clarified by Bazalova-Carter et al. (2019), who state that this threshold applies specifically to tissues with water-like density (soft tissue), where the HU-RED calibration curve has a stable gradient [11], [15], [16].

HU Change Evaluation Against Tolerace

Based on the data presented, fluctuations in the HU value of the plasticine bolus show a very controlled trend. A shift of 10 HU was recorded, equivalent to an increase of 8.3% from the initial value of 120 HU to 130 HU. All evaluation data are summarized in Table 3 for comparison with the standard clinical tolerance parameter of ±20 HU.

Table 3. Evaluation of HU Changes Against Clinical Tolerance Limits

Material	Maximum HU Change	Tolerance Limit	Status	Maximum Dose Change
Plasticine	10 HU	±20 HU	Pass	-0,43%

The comparison results in Table 3 confirm that the fluctuation in the HU value of the plasticine bolus (10 HU) only reaches 50% of the clinical tolerance threshold (±20 HU). The largest dose deviation produced is only -0.43%, well below the significant limit of 1-2%. This proves that plastisin has sufficient density integrity for long-term use in fractionated radiotherapy, as its dosimetric impact remains consistent and within the patient safety corridor.

DISCUSSION

Plasticine Bolus Stability

Test results show that the plasticine bolus experienced the most significant HU value deviation, with a cumulative increase of 8.3% to 9.2% (from 120 HU to ±131 HU). This transformation indicates molecular-

scale structural reorganization due to continuous exposure to 6-MV photon radiation. As a hydrocarbon polymer, plasticine is susceptible to degradation through chain scission and free radical oxidation reactions resulting from ionization. This increase in effective density is thought to be triggered by the loss of volatile components due to the heating effect of radiation energy deposition. In addition, repeated mechanical stress during the bolus placement procedure causes structural compaction or the formation of partial cross-linking. Although chain scission is more dominant, the accumulation of these physical changes collectively increases the density of the material, which ultimately strengthens the radiation attenuation characteristics during the fractionation period.

Dosimetric Implication

Clinically, a 10 HU fluctuation in plasticine affects the precision of dose calculations in TPS through HU-RED calibration curve adjustments. A shift from 120 to 130 HU in the soft tissue spectrum alters the linear attenuation coefficient, which has been shown to reduce the average dose by 0.11%. Although Fitriani et al. (2022) assessed plasticine as effective for certain cases, its plastic deformation characteristics pose a risk of geometric inconsistency in long-term fractionation protocols [7].

Analysis of the HU-dose relationship confirmed a consistent pattern: an increase in HU values inversely correlates with dose at target depth due to enhanced radiation absorption. However, since HU variations in plasticine are marginal and well below the significant threshold, this material is deemed capable of maintaining adequate dosimetric integrity during fractionation without causing clinically significant errors.

Molecular Change Mechanisms

Plasticine is a complex mixture of hydrocarbon polymers, plasticizers, and fillers with a C-C backbone structure that is susceptible to degradation due to ionizing radiation, particularly through oxidation. The increase in HU value from 120 to 130 HU is triggered by the evaporation of volatile components due to local heat from the deposition of radiation energy, which increases the mass fraction of polymers and fillers, thereby increasing the effective density of the material. In addition, molecular restructuring occurs through interactions between chain scission and limited cross-linking formation, resulting in structural compaction. This phenomenon is exacerbated by cumulative mechanical deformation due to repeated bolus insertion and removal procedures, which permanently alter the internal mass distribution and are detected as shifts in the average HU value in the ROI area [17], [18].

Clinical Implications and Recommendations

Although still within the tolerance limit, the plasticine bolus recorded the most significant HU value deviation of 10 HU (8.3%) compared to other materials [11], [19]. This variation, combined with the intrinsic weakness of plasticine in maintaining geometric integrity after mechanical deformation, is a critical consideration for long-term use [20]. In radiotherapy scenarios exceeding 25 fractions, the accumulation of these structural change's risks exceeding the established clinical tolerance limits. Therefore, the use of plasticine as a bolus requires special attention through several guidelines: this material is adequate for short to medium duration protocols (maximum 25 sessions), but each session must be preceded by a physical evaluation in the form of visual inspection and palpation to detect cracks or deformations. Additionally, plastisin is strongly discouraged for clinical cases requiring high geometric precision and positional reproducibility [21]. Medical staff or medical physicists should consider periodic replacement of the bolus if signs of physical degradation appear, especially if the patient's fractionation period is extended beyond the initial plan [19].

CONCLUSION

Research on the stability of plasticine bolus during 25 fractions of 6-MV photon radiotherapy showed a baseline value of 120 ± 9 HU, which places this material in the density spectrum between adipose and soft tissue. During the fractionation period, there was a cumulative increase in HU values of 10 HU (8.3%) with a peak at fraction 15 (131 HU), but all changes were still well below the international clinical tolerance threshold of ±20 HU. The resulting dosimetric impact was minimal, with an average dose reduction of only 0.11% (maximum -0.43%), posing no risk to treatment efficacy as it was below the 1-2% significance threshold. Structurally, these changes were triggered by polymer degradation through chain scission, oxidation, and evaporation of volatile components, which increased the effective density of the material. Although plastisin has adequate HU stability for short to medium-term protocols (≤ 25 fractions), its plastic deformation properties make this material less recommended for cases requiring high geometric precision. Therefore, the use of plastisin must be accompanied by routine physical evaluation through visual inspection and palpation to ensure material integrity during the therapy process.

Declaration by Authors

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