Development of Bolus Made From Silicone Rubber, Glycerol-Gelatin, and Aloe Vera-Gelatin Gel In Post-Mastectomy Breast Cancer Radiotherapy

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Abstract.
This study aims to develop and compare the physical, dosimetric, and applicative characteristics of boluses made from silicone rubber, glycerol-gelatin, and aloe vera-gelatin gel for post-mastectomy breast cancer radiotherapy. The study used an experimental method with variations in material composition and thickness. The samples were boluses of the three materials, while the testing instruments and procedures included measuring relative electron density (RED), surface dose, homogeneity, and evaluating applicative characteristics. Data were analyzed descriptively by comparing the measurement results of each material with a comparison bolus and considering aspects of cost, setting time, form durability, and hygiene. The results showed that silicone rubber was superior in form durability and stability, but had the highest estimated manufacturing cost. Glycerol-gelatin showed advantages in terms of cost and increased surface dose, especially at a ratio of 2:3 with a thickness of 1.5 cm. Aloe vera-gelatin gel also has the potential to be an alternative material by considering the balance of physical and dosimetric characteristics. In conclusion, the three materials have different advantages and limitations, so their selection needs to be adjusted to dosimetric needs, applicative aspects, and costs. Further validation under conditions closer to clinical practice is necessary before routine implementation.

Keywords: Aloe Vera Gel, Breast Cancer, Glycerol Gelatin, Radiotherapy and Silicone Rubber.

I. INTRODUCTION

Radiotherapy is a cancer treatment approach that utilizes ionizing radiation to destroy tumor cells while maintaining the integrity of surrounding healthy tissue. The main principle of radiotherapy is to deliver a dose of radiation that kills cancer cells in a predetermined target volume, while minimizing radiation exposure to surrounding normal tissue. Breast cancer, or mammae carcinoma, is a malignancy that can affect both women and men and develops in the mammary gland tissue, fat tissue, and connective tissue of the breast. Breast cancer remains a serious health problem, especially in women, because it is often associated with malignancies that can lead to death.

According to data from the Global Cancer Observatory, breast cancer ranks first in new cancer cases in Indonesia, with 66,271 cases, or 16.2% of the total 408,661 new cancer cases in 2022. Breast cancer is also the leading cause of cancer deaths in Indonesia, with 22,598 deaths, or 9.3%. Globally, breast cancer ranks first in new cancer cases, with 2,261,419 cases, or 11.7% of the total 19,292,789 new cancer cases. Breast cancer is also the most common malignancy in women, with an incidence rate of 44 cases per 100,000 people.

Cancer treatment can include surgery, chemotherapy, immunotherapy, targeted therapy, hormone therapy, stem cell transplantation, and radiation. Among these modalities, radiotherapy is an important non-surgical therapy in the curative treatment of cancer. Of the 10.9 million people diagnosed with cancer each year worldwide, approximately 50% require radiotherapy, and 60% of these undergo treatment with curative intent. External radiotherapy, including the use of a Linear Accelerator (LINAC) or Cobalt-60, places a radiation source outside the patient's body to reach the tumor area. This requires measuring, calculating, and assessing the radiation dose absorbed by the body through radiation dosimetry to ensure the dose to normal tissue remains controlled.

One way to increase the radiation dose to the body's surface is through the use of a bolus. A bolus increases the radiation dose to the skin, allowing radiation to reach superficial tissues more effectively, especially in patients with asymmetrical body contours or after surgical procedures. A bolus is a material that resembles human skin and is placed on the skin's surface during radiation therapy to increase the skin dose if

necessary. In post-mastectomy breast cancer radiotherapy using 6 MV photons, the skin-sparing effect results in a relatively low surface dose, making the use of a bolus crucial for improving dose coverage in superficial target areas.

However, boluses used clinically still face several limitations. Thermoplast boluses used in research facilities are manufactured by layering, making them stiff and less flexible in conforming to body contours. This can cause discomfort for patients, especially in sensitive areas, and creates additional space between the skin surface and the bolus due to tumor shrinkage during therapy. In addition to thermoplast, plasticine boluses are also used in some hospitals due to their greater malleability, but their use has been reported to cause skin discoloration, dryness, hardening, and cracking after multiple irradiation fractions. These changes in physical properties have the potential to cause dose inhomogeneity and reduce patient comfort and safety. Therefore, alternative bolus materials are needed that are more flexible, physically stable, skin-safe, and have measurable dosimetric characteristics.

Silicone Rubber has been widely explored as an alternative bolus due to its better elasticity compared to thermoplast and plasticine, its ability to conform to body contours, and its ability to minimize air gaps. Research by Leony et al. (2022) showed that silicone rubber has good dosimetric equivalence with commercial boluses and produces a more stable surface dose consistency. Furthermore, glycerol and gelatin-based boluses have also been developed as alternatives due to their biocompatibility, ease of molding, and low production costs. Oliveira et al. (2020) developed a bolus from water, bidistilled glycerol, and gelatin that demonstrated dose equivalence to soft tissue, with dose deviations below 6% for 6 MV photons and 18 MeV electrons. Kong et al. (2019) also reported that hydrogel-based boluses and 3D-printed silicone boluses were able to improve radiation dose compliance compared to standard boluses. On the other hand, aloe vera gel has a very high water content, which is around 98%, so it has the potential to be developed as a gel-based material. Aloe vera gel has also been reported to reduce the severity of radiation-induced dermatitis in patients undergoing chemoradiotherapy. Other findings suggest that aloe vera has the potential to help reduce skin complaints in radiotherapy patients, such as erythema, pruritus, and desquamation. However, the use of aloe vera gel as a component of radiotherapy boluses requires further testing, particularly regarding physical characteristics and dosimetry.

This study aims to develop and compare boluses made from Silicone Rubber, glycerol-gelatin, and aloe vera-gelatin gel as alternative external radiotherapy boluses for post-mastectomy breast cancer using 6 MV energy photons. Evaluations were conducted on the Relative Electron Density (RED) value, surface dose percentage, material homogeneity tendency, expert validation, and applicability aspects, with thermoplast as a clinical comparator and conditions without a bolus as a baseline. This study is important because the results can be an initial basis for radiotherapy personnel and medical physicists in assessing the potential of alternative bolus materials that are more adaptive to the patient's body contour. The novelty of this study lies in the development and comparison of glycerol-gelatin and aloe vera-gelatin gel as radiotherapy bolus materials, especially at 6 MV energy photons, which based on the references used have not been studied specifically. Thus, this study is expected to provide an initial contribution in the development of a more flexible, stable, and applicable external radiotherapy bolus before further testing in the clinical stage.

II. METHODS

This study employed a comparative experimental method with a Research and Development (R&D) approach using the ADDIE model, which comprises five stages: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model provides a systematic framework for product development, from needs analysis to product evaluation [10]. This study aimed to develop and compare the physical characteristics and dosimetric performance of radiotherapy boluses made from silicone rubber, glycerol-gelatin, and aloe vera-gelatin gel for post-mastectomy breast cancer radiotherapy using 6 MV photon beams.

Testing was conducted by comparing the developed boluses with thermoplast as a clinical reference and a condition without a bolus as the baseline. The assessed parameters included CT Number, Relative Electron Density (RED), material homogeneity, surface dose, and expert validation results. RED was

determined from the relationship between CT Number and relative electron density using the CT-to-RED calibration curve available at the research facility [11]. This study was limited to preliminary product development and feasibility evaluation and did not involve direct application to patients.

The research instruments included bolus fabrication equipment, digital scales, molds, a GE Optima CT 580 CT-Simulator, a Linear Accelerator (LINAC) delivering 6 MV photon beams, a solid water phantom, and a Markus ionization chamber. The materials consisted of RTV-52 silicone rubber, an RTV catalyst, gelatin, glycerol, aloe vera gel, and propylene glycol.

Quantitative data were obtained from CT Number measurements, RED calculations, surface dose measurements, and validator assessments. Qualitative data included descriptions of physical characteristics, material homogeneity, and expert validation findings. Dosimetric testing was conducted under controlled irradiation conditions using an ionization chamber-based measurement system in accordance with the dosimetry principles described in the IAEA TRS-398 protocol [12].

The instrument's content validity was analyzed using the Item-level Content Validity Index (I-CVI) and Scale-level Content Validity Index (S-CVI). The percentage of eligibility was calculated using the formula:

$$P = \frac{\sum x}{\sum xi} x\ 100\%$$

Information :

P: percentage (what is sought)

Σ : total number of response answers in 1 item

Σ : total number of highest answer scores in 1 item

100 : constant number

The measurement results were analyzed descriptively and comparatively based on the type of material, composition variation, and bolus thickness to assess the physical characteristics and dosimetric performance.

The research population comprised external bolus materials with potential applications in radiotherapy. The research samples consisted of thermoplast as the clinical reference and boluses developed from silicone rubber, glycerol-gelatin, and aloe vera-gelatin gel. The developed boluses measured 10 × 10 cm, with thickness variations of 0.5, 1.0, and 1.5 cm. For gelatin-based formulations, composition ratios of 1:3 and 2:3 were evaluated, whereas the 3:1 ratio was discontinued because the prototype could not be successfully fabricated. Thermoplast was tested at a thickness of 0.5 cm, according to the practices and material availability at the research facility.

The research procedure followed the five stages of the ADDIE model.

1. Analysis: The requirements for alternative bolus materials were identified based on the limitations of thermoplast in conforming to body surface contours. The physical and dosimetric criteria for evaluating the developed materials were also established.
2. Design: The materials, composition ratios, bolus dimensions of 10 × 10 cm, thickness variations, and measurement parameters were determined according to the research design.
3. Development: Prototypes made from silicone rubber, glycerol-gelatin, and aloe vera-gelatin gel were fabricated. Each prototype was examined for physical appearance, structural stability, and homogeneity before further testing.
4. Implementation: The samples were scanned using a CT-Simulator at 120 kV and 240 mA to obtain CT Number values and determine RED using the CT-to-RED calibration curve of the research facility [11]. Dosimetric testing was performed using a 6 MV photon LINAC, a solid water phantom, and a Markus ionization chamber at a source-to-surface distance (SSD) of 100 cm and a field size of 10 × 10 cm^2. Measurements were conducted under three conditions: without a bolus, with thermoplast, and with each developed bolus. Each condition was measured three times, after which the mean and standard deviation were calculated. The measurements followed the principles of absorbed-dose determination using an ionization chamber system as described in the IAEA TRS-398 protocol [12].
5. Evaluation: The CT Number, RED, material homogeneity, and surface dose were compared across material types and thickness variations. Medical physicists and radiotherapy technologists (RTTs) assessed the physical characteristics, dosimetric performance, structural stability, and ease of use of the developed boluses. The

evaluation results were used to determine their preliminary feasibility as alternative radiotherapy bolus materials. This assessment did not constitute direct evidence of clinical safety or effectiveness in patients.

III. RESULT AND DISCUSSION

Bolus Product Development Results

1. Analysis

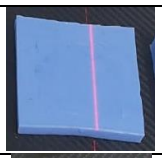
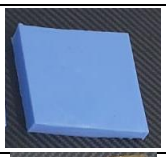
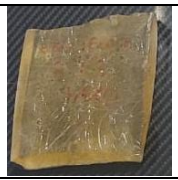
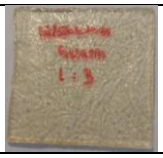
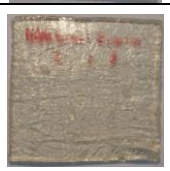
A research analysis was conducted to identify the need for alternative bolus materials for post-mastectomy breast cancer radiotherapy. Thermoplast has limitations in conforming to body contours due to its relatively rigid nature, potentially creating air gaps that affect dose distribution.

Therefore, three candidate bolus materials were developed: silicone rubber, glycerol-gelatin, and aloe vera gel-gelatin. All three were evaluated based on CT number, relative electron density (RED), surface dose, homogeneity, expert validation, and applicability to determine their initial feasibility as alternative radiotherapy boluses.

2. Design (Product Design)

The design phase was carried out by designing a bolus made of silicone rubber, glycerol-gelatin, and aloe vera gel-gelatin, using thermoplast as a clinical comparison. The bolus was made in the form of a 10 × 10 cm sheet with varying thicknesses of 0.5 cm, 1.0 cm, and 1.5 cm, while thermoplast used a thickness of 0.5 cm and conditions without a bolus as a baseline. Gelatin-based materials used a composition ratio of 1:3 and 2:3, while the 3:1 ratio was discontinued because the prototype failed to form. This design was used to evaluate CT Number, RED, homogeneity, and surface dose under 6 MV photon irradiation.

Table 1. Variations and Dimensions of Bolus Samples Based on Material, Composition Ratio, and Thickness

Material	Ratio	0.5 cm	1 cm	1.5 cm
Thermoplastic	-		-	-
Silicone Rubber	-			
Glycerol – Gelatin	1:3			
	2:3			
	3:1	Not continued due to printing failure		
Aloe Vera Gel – Gelatin	1:3			
	2:3			
	3:1	Not continued due to printing failure		

Information:"-" = not used/not available in this study.

3. Development (Product Development)

The Development stage was carried out by making a bolus prototype made of Silicone Rubber, glycerol-gelatin, and aloe vera gel-gelatin measuring 10 × 10 cm with thickness variations of 0.5 cm, 1.0 cm, and 1.5 cm. Gelatin-based materials used a ratio of 1:3 and 2:3, while the 3:1 ratio was discontinued due to the prototype's instability. Thermoplast with a thickness of 0.5 cm was used as a clinical comparison and conditions without bolus as a baseline. All prototypes were then tested for their physical and dosimetric characteristics and validated by experts at the Implementation and Evaluation stages.

4. Implementation (Product Implementation and Testing)

The implementation phase was conducted to ensure that the bolus assessment instrument/questionnaire used in this study met the development objectives and was suitable for use as part of the bolus product feasibility evaluation. Validation was conducted by distributing questionnaires to expert validators using a 1–4 rating scale (1 = poor, 2 = sufficient, 3 = good, 4 = very good). The validation panel consisted of three validators, namely two Medical Physicists and one Radiotherapy Technologist (RTT), so that the assessment covered both physical-dosimetric aspects and clinical application aspects.

A. Validator Characteristics

Table 2. Characteristics of Expert Validators

Validator	Profession	Last education	Experience in the field of radiotherapy	Field of competence
Validator 1	Medical Physicist	Master of Medical Physics	8 Years	Medical physics and radiotherapy dosimetry
Validator 2	Medical Physicist	Master of Medical Physics	5 years	Medical physics and radiotherapy dosimetry
Validator 3	*Radiotherapy Technologist*(RTT)	D-IV Radiology Imaging Technology	11 years	Radiotherapy techniques and clinical applications of bolus

B. Validity of Assessment Instruments

Before the questionnaire was used to assess the feasibility of the bolus product, a content validity test was conducted using the Content Validity Index (CVI), with a dichotomy of relevant (scores 3–4) and irrelevant (scores 1–2). Validity was calculated at the item level (I-CVI) and summarized at the instrument level (S-CVI). The results showed that all questionnaire statement items were rated as relevant by the validators, with each item achieving an I-CVI of 1.00 and universal agreement (UA = 1). Therefore, the assessment instrument was declared valid and suitable for use in evaluating the feasibility of the bolus product in the subsequent stage.

C. Expert validation results by medical physicists

Table 3. Summary of Validation by Medical Physicist 1

Aspect	*Silicone Rubber*	Glycerol-gelatin	Aloe vera gel-gelatin
Physical Characteristics and Shape Stability	14	12	10
Material Homogeneity Based on CT Number/ROI Results	12	10	8
RED Compliance with Soft Tissue and Clinical Comparators	11	12	12
6 MV Photon Surface Dose Performance	15	16	15
Ease of Application and Potential for Implementation	12	13	13
Final Product Feasibility Assessment	4	3	3
Total	68	66	61
Maximum Score	84	84	84
Eligibility Percentage	80.95%	78.57%	72.62%
Category	Very Worthy	Very Worthy	Worthy

Based on Table 3, Silicone Rubber obtained a total score of 68 with a feasibility percentage of 80.95% and is included in the very feasible category. Glycerol-gelatin obtained a total score of 66 with a feasibility percentage of 78.57% and is included in the very feasible category, while aloe vera gel-gelatin obtained a total score of 61 with a feasibility percentage of 72.62% and is included in the feasible category. Medical Physicist 1 gave the highest rating to Silicone Rubber, while aloe vera gel-gelatin obtained a lower score, especially in the aspects of physical characteristics, shape stability, and material homogeneity.

Table 4. Summary of Validation by Medical Physicists 2

Aspect	*Silicone Rubber*	Glycerol-gelatin	Aloe vera gel-gelatin
Physical Characteristics and Shape Stability	13	13	13
Material Homogeneity Based on CT Number/ROI Results	15	15	15
RED Compliance with Soft Tissue and Clinical Comparators	16	16	16
6 MV Photon Surface Dose Performance	16	16	16
Ease of Application and Potential for Implementation	15	15	15
Final Product Feasibility Assessment	4	4	4
Total	79	79	79
Maximum Score	84	84	84
Eligibility Percentage	94.05%	94.05%	94.05%
Category	Very Worthy	Very Worthy	Very Worthy
Category	Very Worthy	Very Worthy	Very Worthy

Based on Table 4, the three bolus materials obtained the same total score, namely 79 out of a maximum score of 84. The feasibility percentage of each material was 94.05% and was included in the very feasible category. These results indicate that according to the assessment of Medical Physicist 2, Silicone Rubber, glycerol-gelatin, and aloe vera gel-gelatin had the same level of feasibility based on aspects of physical characteristics, homogeneity, RED suitability, surface dose performance, ease of application, and final product assessment.

D. Expert validation results by Radiotherapy Technologist (RTT)

Table 5. Recapitulation of validation by RTT

Aspect	*Silicone Rubber*	Glycerol-gelatin	Aloe vera gel-gelatin
Physical Characteristics and Shape Stability	16	15	16
Material Homogeneity Based on CT Number/ROI Results	15	12	13
RED Compliance with Soft Tissue and Clinical Comparators	14	12	12
6 MV Photon Surface Dose Performance	12	15	16
Ease of Application and Potential for Implementation	12	15	16
Final Product Feasibility Assessment	3	3	4
Total	76	73	77
Maximum Score	84	84	84
Eligibility Percentage	90.48%	86.90%	91.67%
Category	Very Worthy	Very Worthy	Very Worthy

Based on Table 5, Silicone Rubber obtained a total score of 76 with a feasibility percentage of 90.48%, glycerol–gelatin obtained a total score of 73 with a percentage of 86.90%, and aloe vera gel–gelatin obtained a total score of 77 with a percentage of 91.67%. All three materials are included in the very feasible category.

Aloe vera gel–gelatin received the highest rating from the RTT, particularly in terms of surface dose performance, ease of application, implementation potential, and final product feasibility assessment. Meanwhile, glycerol–gelatin received lower scores, particularly in terms of material homogeneity and RED compliance.

E. Combined recapitulation of validator assessments

Table 6. Combined Expert Validation Recapitulation

Bolus	Total Combined Score	Maximum Score	Percentage	Category
Silicone Rubber	223	252	88.49%	Very worthy
Glycerol – Gelatin	218	252	86.51%	Very worthy
Aloe Vera Gel - Gelatin	217	252	86.11%	Very worthy

Based on the recapitulation of the validator's assessment, all developed boluses were categorized as very feasible, with Silicone Rubber scoring 88.49%, glycerol–gelatin scoring 86.51%, and aloe vera gel–gelatin scoring 86.11%. A score difference of less than 3% indicates a relatively equal feasibility level. The assessment variation was influenced by the validator's professional focus, namely medical physicists who emphasize physical and dosimetric aspects, while Radiotherapy Technologists (RTTs) focus more on

applicability and ease of use. Thus, all three materials have initial feasibility as alternative candidates for external radiotherapy boluses based on expert validation.

F. Evaluation Stage (Product Evaluation)

The developed bolus consisting of Silicone Rubber, glycerol-gelatin, and aloe vera gel-gelatin with a ratio of 1:3 and 2:3 was successfully made at a thickness of 0.5 cm, 1.0 cm, and 1.5 cm. The 3:1 ratio was discontinued because the prototype failed to be printed. The measurement results showed that the surface dose increased from 16.02% in conditions without bolus and 80.58% in thermoplast to 82.18%–88.77% at a thickness of 0.5 cm, 95.10%–98.27% at a thickness of 1.0 cm, and 96.52%–99.88% at a thickness of 1.5 cm. The highest value was obtained at a glycerol–gelatin ratio of 2:3 with a thickness of 1.5 cm at 99.88%.

Although RED values varied between materials and thicknesses, all boluses increased surface dose and were classified as very acceptable based on expert validation. Therefore, these materials have the potential to be alternative external bolus radiotherapy. However, further testing regarding the air gap, material stability, dose distribution in the TPS, and safety and comfort is still needed before clinical application.

Bolus Characteristics Reviewed from Bolus Thickness Variations

Bolus characteristics were evaluated based on CT Number, Relative Electron Density (RED), homogeneity, and surface dose with thermoplast as a clinical comparison. CT Number measurements were performed using a CT-Simulator at 120 kV and 240 mA parameters. DICOM images were analyzed using Weasis through five Region of Interest (ROI) points, namely the 12, 3, 6, 9 o'clock positions, and the center of the bolus, with a uniform ROI size of 3.64 mm². The HU values from the five points were averaged to determine RED using a conversion equation according to the CT Number value.

Variations in HU values between ROIs, whether positive or negative, do not directly hinder RED calculations because the conversion uses the average HU value. However, differences in HU between points can indicate material density irregularities due to air bubbles, small voids, or uneven material mixing. Therefore, HU variations are also used to evaluate the tendency of bolus homogeneity. The smaller the variation in HU between ROIs, the better the tendency of material homogeneity.

1. CT Number bolus value

The CT Number value for the bolus was obtained from measuring five ROI points on each bolus sample. The CT Number values from each ROI were then summed and the average value calculated. This average CT Number value was used as the basis for calculating the Relative Electron Density (RED) for each material and bolus thickness variation.

***A. CT Number* Thermoplast Bolus**

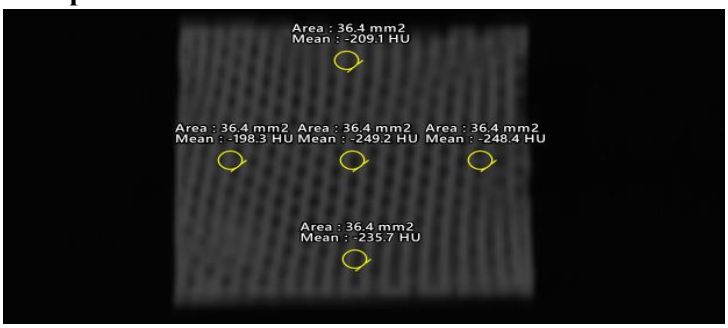


Fig. 1. ROI results on thermoplast bolus

Table 7. ROI Results on Thermoplast Bolus

N	Thermoplast Bolus
	0.5 cm
1	-209.1
2	-248.4
3	-235.7
4	-198.3
5	-249.2
Amount	-1140.7
Amount Average	-228.14

The calculation of the RED value on a thermoplast bolus sample with a thickness of 0.5 cm was carried out based on the CT Number (NCT/HU) value from the ROI measurement results in Weasis. The average NCT value in this sample was -228.14, so the conversion to RED used Equation (2) because the CT Number value was <100, as follows:

$\rho b = 1{,}000 + 0{,}001\ NCT$

$\rho b = 1{,}000 + 0{,}001(-228{,}14)$

$\rho b = 0.77186$

Based on these calculations, the RED value of a 0.5 cm thick thermoplast bolus is 0.77186. When compared to Table 1, this value is lower than the RED of breast tissue of 0.976, muscle of 1.043, liver of 1.052, and dense bone of 1.512. Thus, the RED value of thermoplast in this study has not approached the RED value of soft tissue based on the reference in Table 1.

Although the RED value of thermoplast is lower than the soft tissue reference value, thermoplast is still used as a clinical comparator because it is a bolus routinely used in research facilities. Therefore, the interpretation of the feasibility of the bolus developed in this study is based not only on the RED value but also on the bolus's ability to increase surface dose, material homogeneity, and expert validation results.

B. *CT Number* Silicone Rubber Bolus

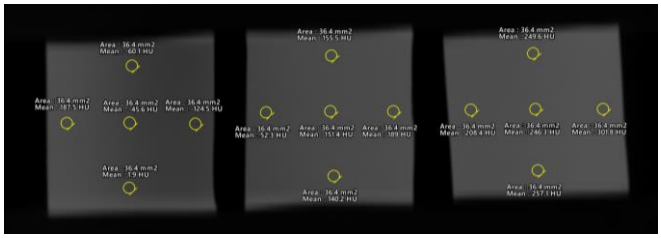


Fig. 2. ROI results on silicone rubber bolus

Table 8. ROI Results on Silicone Rubber Bolus

N	Silicone Rubber Bolus		
	0.5 cm	1 cm	1.5 cm
1	-60.1	155.5	249.6
2	-124.5	189	301.8
3	1.9	140.2	257.1
4	187.5	52.3	208.4
5	-45.6	151.4	246.3
Amount	-40.8	688.4	1263.2
Amount average	-8.16	137.68	252.64
RED Value	0.99184	1.11809	1,17327

Based on Table 8, the average CT Number values of Silicone Rubber boluses at thicknesses of 0.5 cm, 1.0 cm, and 1.5 cm were −8.16 HU; 137.68 HU; and 252.64 HU, respectively. The conversion results showed RED values of 0.99184; 1.11809; and 1.17327, respectively.

The RED value of silicone rubber increased with increasing bolus thickness. A thickness of 0.5 cm yielded the closest RED value to breast tissue at 0.976, while thicknesses of 1.0 cm and 1.5 cm showed higher RED values than the reference soft tissue.

C. *CT Number* Glycerol – Gelatin Bolus

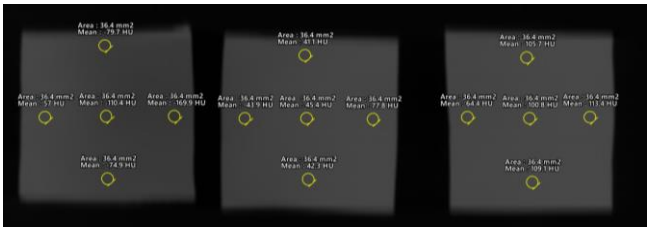


Fig. 3. ROI results on Glycerol-Gelatin Bolus with a ratio of 1:3

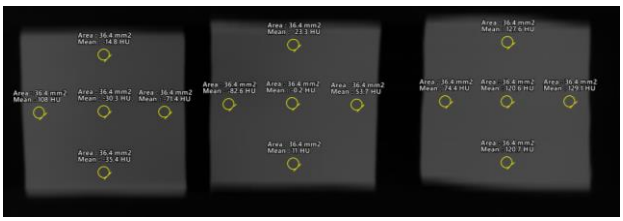


Fig. 4. ROI results on Glycerol – Gelatin Bolus ratio 2:3

Table 9. ROI Results on Glycerol-Gelatin Bolus

N	Glycerol-Gelatin Bolus					
	1:3			2:3		
	0.5 cm	1 cm	1.5 cm	0.5 cm	1 cm	1.5 cm
1	-79.7	41.1	105.7	-14.8	-23.3	127.6
2	-169.9	77.8	113.4	-71.4	53.7	129.1
3	-74.9	42.3	109.1	-35.4	11	120.7
4	57	-43.9	64.4	108	-82.6	74.4
5	-110.4	45.4	100.8	-30.3	-0.2	120.7
Amount	-377.9	162.7	493.4	-43.9	-41.4	572.5
Amount average	-75.58	32.54	98.68	-8.78	-8.28	114.5
RED Value	0.92442	1.03254	1.09868	0.99122	0.99172	1,10696

Based on Table 9, the glycerol–gelatin bolus with a 1:3 ratio has an average CT Number value of −75.58 HU; 32.54 HU; and 98.68 HU at a thickness of 0.5 cm, 1.0 cm, and 1.5 cm. The calculation results show RED values of 0.92442; 1.03254; and 1.09868, respectively.

At a 2:3 ratio, the average CT Number values at 0.5 cm, 1.0 cm, and 1.5 cm thicknesses were −8.78 HU; −8.28 HU; and 114.50 HU, respectively, with RED values of 0.99122; 0.99172; and 1.10696. The RED values closest to breast tissue were obtained at a 2:3 ratio at 0.5 cm and 1.0 cm thicknesses. In general, RED values tended to increase at 1.5 cm thickness.

D. *CT Number* Aloe Vera Bolus – Gelatin

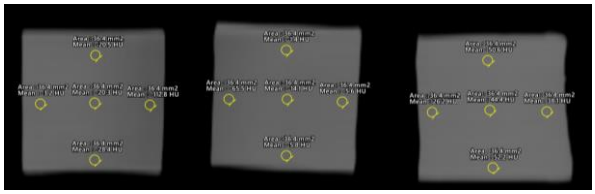


Fig. 5. ROI results on Aloe Vera Gel Bolus – Gelatin ratio 1:3

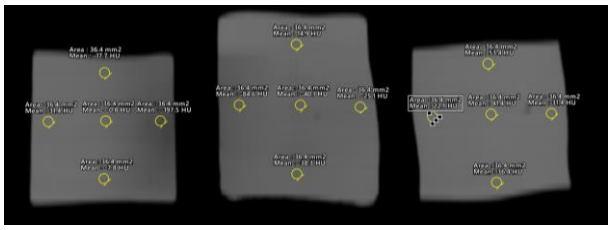


Fig. 6. ROI results on Aloe Vera Gel Bolus – Gelatin ratio 2:3

Table 10. ROI Results on Aloe Vera-Gelatin Bolus

N	Aloe Vera Gelatin Bolus					
	1:3			2:3		
	0.5 cm	1 cm	1.5 cm	0.5 cm	1 cm	1.5 cm
1	-20.5	-1.4	50.6	-17.7	14.9	53.4
2	-112.8	-5.6	38.1	-197.5	-25.1	31.4
3	-28.4	-5.8	52.2	-7.8	-38.3	36.4
4	-3.2	-65.5	26.2	31.4	-84.6	22.1
5	-20.3	-14.1	44.4	-0.8	-40.1	41.4
Amount	-185.2	-92.4	211.5	-192.4	-173.2	184.7
Amount average	-37.04	-18.48	42.3	-38.48	-34.64	36.94

RED Value	0.96296	0.98152	1.04230	0.96152	0.96536	1.03694

Based on Table 10, the aloe vera gel-gelatin bolus with a ratio of 1:3 has an average CT Number value of −37.04 HU; −18.48 HU; and 42.30 HU at a thickness of 0.5 cm, 1.0 cm, and 1.5 cm. The calculation results show RED values of 0.96296; 0.98152; and 1.04230, respectively.

At a ratio of 2:3, the average CT Number values at thicknesses of 0.5 cm, 1.0 cm, and 1.5 cm were −38.48 HU; −34.64 HU; and 36.94 HU, respectively, with RED values of 0.96152; 0.96536; and 1.03694. The RED value closest to breast tissue was obtained at a ratio of 1:3 at a thickness of 1.0 cm at 0.98152, while the value closest to muscle tissue was obtained at a ratio of 1:3 at a thickness of 1.5 cm at 1.04230

2. Percentage surface dose

Table 11. Surface Dose Measurement Results, Mean Values, and Standard Deviations

Condition/Material	Ratio	Thickness	Mean dose (mGy)	SD (mGy)	Surface Dose Percentage (%)	SD(%)
No bolus	-	-	320.33	0.23	16.02	0.01
Thermoplastic	-	0.5	1611.67	0.58	80.58	0.03
Silicone Rubber	-	0.5	1643.67	0.58	82.18	0.03
	-	1.0	1904.67	0.58	95.23	0.03
	-	1.5	1930.33	0.58	96.52	0.03
Glycerol–gelatin	1:3	0.5	1703.67	0.58	85.18	0.03
		1.0	1959.67	0.58	97.98	0.03
		1.5	1997.33	0.58	99.87	0.03
	2:3	0.5	1775.33	0.58	88.77	0.03
		1.0	1965.33	0.58	98.27	0.03
		1.5	1997.67	2.31	99.88	0.12
Aloe vera gel–gelatin	1:3	0.5	1723.00	1.00	86.15	0.05
		1.0	1902.00	0.00	95.10	0.00
		1.5	1981.67	0.58	99.08	0.03
	2:3	0.5	1744.67	0.58	87.23	0.03
		1.0	1927.00	0.00	96.35	0.00
		1.5	1994.67	1.15	99.73	0.06

Based on Table 11, the condition without a bolus resulted in a surface dose percentage of 16.02%, while the 0.5 cm thick thermoplast produced a percentage of 80.58%. All developed boluses produced a higher surface dose percentage than the condition without a bolus and the thermoplast.

At a thickness of 0.5 cm, the percentage of the developed bolus surface dose ranged from 82.18% to 88.77%. At a thickness of 1.0 cm, the percentage of the surface dose increased to 95.10% to 98.27%, while at a thickness of 1.5 cm it ranged from 96.52% to 99.88%. The highest percentage of the surface dose was obtained at a glycerol–gelatin ratio of 2:3 at a thickness of 1.5 cm, which was 99.88%.

The standard deviation of all measurements ranged from 0.00 to 2.31 mGy, equivalent to 0.00% to 0.12%. This indicates relatively low variation between replicates. Complete calculations of the mean, standard deviation, and surface dose percentage were performed.

For example, the results of surface dose measurements without bolus in three irradiations are 320.2 mGy; 320.2 mGy; and 320.6 mGy. The average dose value is calculated as follows:

$$\bar{D} = \frac{320{,}2 + 320{,}2 + 320{,}6}{3}$$

$$\bar{D} = 320{,}33 \text{ mGy}$$

The percentage of surface dose is calculated against the dose at a maximum depth of 2000 mGy:

$$\%D_{\text{surface}} = \frac{320{,}33}{2000} \times 100\%$$

$$\%D_{\text{surface}} = 16{,}02\%$$

Thus, the no-bolus condition resulted in a surface dose percentage of 16.02%. The complete surface dose calculations for thermoplast and all developed boluses are presented in detail.

Bolus Homogeneity Based on Thickness Variation

The tendency of bolus homogeneity in this study was assessed descriptively based on variations in CT Number values at five Region of Interest (ROI) points, namely at 12 o'clock, 3 o'clock, 6 o'clock, 9 o'clock, and the center of the bolus. The CT Number values at each ROI point have been presented in Tables 6 to 9. The smaller the difference in CT Number values between ROIs in the same sample, the better the tendency of homogeneity of the bolus material.

The measurement results showed that the 0.5 cm thick Silicone Rubber bolus had a greater variation in CT Number values between ROIs compared to 1.0 cm and 1.5 cm thicknesses. In glycerol–gelatin ratios of 1:3 and 2:3, the CT Number values at 1.5 cm thickness tended to be closer than those at 0.5 cm and 1.0 cm. The same trend was also found in aloe vera gel–gelatin bolus ratios of 1:3 and 2:3.

Overall, most boluses with a thickness of 1.5 cm showed smaller variations in CT Number values between ROIs, thus tending to have better homogeneity than those with thinner thicknesses. However, the homogeneity assessment in this study was still descriptive based on five ROI points andhave not used specific quantitative parameters, such as the coefficient of variation or homogeneity index.

Initial Suitability of Bolus as a Candidate for Bolus Radiotherapy

The initial feasibility of the developed bolus was assessed based on physical characteristics in the form of CT Number and Relative Electron Density (RED) values, material homogeneity tendencies, the ability to increase surface dose upon 6 MV energy photon irradiation, and expert validation results. The results of each test have been presented in Tables 2 to 11.

Physically, each material exhibits different RED values based on its composition and thickness. Some bolus variations have RED values closer to those of soft tissue, particularly breast and muscle tissue. From a dosimetric perspective, all developed boluses increased surface dose compared to the unbolus condition and produced values equivalent to or higher than those of thermoplast as a clinical comparator. Increasing bolus thickness also tended to be accompanied by increased surface dose and a tendency toward better homogeneity in most samples.

Expert validation results indicate that silicone rubber, glycerol-gelatin, and aloe vera-gelatin gel obtained a combined highly feasible category. Based on these overall results, all three materials have initial feasibility as candidates for external radiotherapy boluses. However, this feasibility is still limited to the results of physical and dosimetric testing using a CT simulator, LINAC, Markus chamber, and solid water phantom. Therefore, the results of this study cannot be interpreted as direct clinical feasibility in patients and still require further testing.

IV. DISCUSSION

Bolus Product Development Results

This Research and Development (R&D) study resulted in the development of external radiotherapy bolus prototypes made from silicone rubber, glycerol-gelatin, and aloe vera-gelatin gel for post-mastectomy breast cancer radiotherapy using 6 MV photon beams, with thermoplast serving as the clinical comparator. The development aimed to produce bolus materials capable of increasing surface dose, conforming to body contours, and minimizing air gaps that could affect radiation dose distribution. These objectives are consistent with Kong et al. [8], who discussed the role of bolus materials in increasing skin dose and the limitations of flat boluses in conforming to irregular body contours.

The prototypes were successfully fabricated with thickness variations of 0.5, 1.0, and 1.5 cm. The gelatin-based formulations used composition ratios of 1:3 and 2:3, whereas the 3:1 ratio was excluded because the prototype could not be successfully fabricated. This finding highlights the importance of optimizing material composition during bolus development, consistent with Oliveira et al. [7], who examined the influence of formulation on bolus density, homogeneity, and flexibility. All prototypes were subsequently evaluated using a CT-Simulator to obtain CT Number and RED values, followed by surface dose measurements using a 6 MV photon LINAC, a Markus ionization chamber, and a solid water phantom. The resulting data were used

to assess the physical characteristics, material homogeneity, dosimetric performance, and preliminary feasibility of the developed bolus materials.

Bolus Characteristics Reviewed from Bolus Thickness Variations

1. Relative Electron Density (RED) Value of Bolus Against Thermoplast

Table 12. Average CT Number and Relative Electron Density (RED) Bolus Values for Thermoplast

Bolus Material	Ratio	Thickness	RED	RED Interpretation
Thermoplastic	-	0.5 cm	0.77186	Lower than breast tissue and muscle
Silicone Rubber	-	0.5 cm	0.99184	Approaching breast tissue
		1.0 cm	1.11809	Higher than breast tissue and muscle
		1.5 cm	1,17327	Higher than breast tissue and muscle
Glycerol–gelatin	1:3	0.5 cm	0.92442	Lower than breast tissue
		1.0 cm	1.03254	Approaching muscle tissue
		1.5 cm	1.09868	Approaching muscle tissue
	2:3	0.5 cm	0.99122	Approaching breast tissue
		1.0 cm	0.99172	Approaching breast tissue
		1.5 cm	1,10696	Higher than breast tissue and muscle
Aloe vera gel–gelatin	1:3	0.5 cm	0.96296	Approaching breast tissue
		1.0 cm	0.98152	Closest to breast tissue
		1.5 cm	1.0423	Closest to muscle tissue
	2:3	0.5 cm	0.96152	Approaching breast tissue
		1.0 cm	0.96536	Approaching breast tissue
		1.5 cm	1.03694	Approaching muscle tissue

The RED values presented in Table 12 varied according to material type, composition ratio, and thickness. Thermoplast exhibited a RED value of 0.77186 and was included as a comparison material because it is routinely used in the research facility, rather than being considered an ideal reference based on RED. This distinction is important when interpreting the relative electron density of the developed boluses.

For silicone rubber, the RED value increased with increasing thickness. At a thickness of 1.0 cm, the RED value reached 1.11809, which was close to the value reported by Fajriani et al. [13], namely 1.114 ± 0.021. Differences in RED values across other variations may be attributable to material composition, fabrication techniques, molding conditions, and internal density distribution.

For glycerol-gelatin boluses, the 2:3 composition at thicknesses of 0.5 and 1.0 cm exhibited RED values closer to those of breast tissue, whereas the 1:3 composition at a thickness of 1.0 cm was closer to muscle tissue. These findings are consistent with Oliveira et al. [7], who highlighted the importance of density, homogeneity, flexibility, and dosimetric characteristics in the development of gelatin-based bolus materials.

The aloe vera-gelatin gel boluses also demonstrated RED values approaching those of reference tissues. The 1:3 composition at a thickness of 1.0 cm most closely approximated breast tissue, whereas the 1.5 cm variation most closely approximated muscle tissue. Because this formulation represents a novel development in the present study, direct comparisons with previous studies specifically investigating aloe vera-based radiotherapy boluses remain limited. Nevertheless, its development is conceptually related to the investigation by Kong et al. [8] concerning the potential application of hydrogel-based materials as radiotherapy boluses. Further investigations are required to evaluate water loss, dimensional deformation, physical stability, and storage durability.

Overall, the suitability of the developed boluses varied according to their RED values, material compositions, and thicknesses. Therefore, material suitability cannot be established solely on the basis of RED similarity to reference tissues. A comprehensive assessment should also consider surface dose performance, material homogeneity, expert validation, and practical applicability to identify the most promising formulation for further development.

2. Surface Dose of 6 MV Photons Based on Bolus Thickness Variations

Surface dose is an important parameter for evaluating the function of radiotherapy boluses, as boluses can reduce the skin-sparing effect of 6 MV photons by shifting the build-up region closer to the skin surface. In this study, measurements using a 6 MV photon LINAC, a Marcus chamber, and a solid water phantom

showed that the no-bolus condition resulted in a surface dose of 16.02% relative to dmax, whereas the use of a 0.5 cm-thick thermoplast bolus increased the surface dose to 80.58%. These findings indicate that the use of a bolus can effectively increase the surface dose, particularly for superficial targets such as the chest wall following mastectomy.

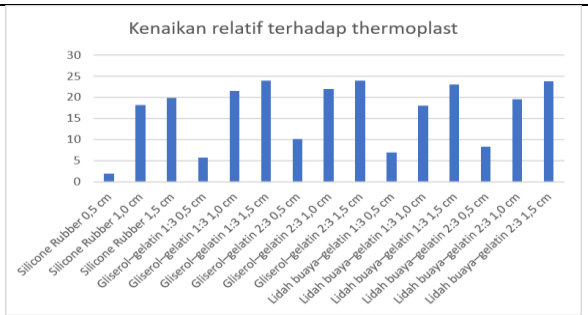
Table 13. Percentage of 6 MV Photon Surface Dose Based on Material and Bolus Thickness Mean ± SD

Bolus Material	Ratio	0.5 cm	1.0 cm	1.5 cm
No bolus	-	16.02 ± 0.01	-	-
Thermoplastic	-	80.58 ± 0.03	-	-
Silicone Rubber	-	82.18 ± 0.03	95.23 ± 0.03	96.52 ± 0.03
Glycerol–gelatin	1:3	85.18 ± 0.03	97.98 ± 0.03	99.87 ± 0.03
Glycerol–gelatin	2:3	88.77 ± 0.03	98.27 ± 0.03	99.88 ± 0.12
Aloe vera gel–gelatin	1:3	86.15 ± 0.05	95.10 ± 0.00	99.08 ± 0.03
Aloe vera gel–gelatin	2:3	87.23 ± 0.03	96.35 ± 0.00	99.73 ± 0.06

The standard deviation of three surface dose measurements ranged from 0.00% to 0.12%, indicating good consistency of the measurement results. Based on Table 13, all developed boluses were able to increase the surface dose compared to the condition without bolus and 0.5 cm thermoplast. The dose increase occurred with increasing bolus thickness, with values reaching 96.52%–99.88% at 1.5 cm thickness. However, the dose increase from 1.0 cm to 1.5 cm thickness was relatively smaller, indicating a tendency to reach a surface dose plateau. Comparisons with thermoplast were made based on the percentage point difference and relative increase to evaluate the dose increase produced by each bolus.

Table 14. Increase in Percentage of Bolus Surface Dose of Development Results against 0.5 cm Thermoplast

Bolus Material	Ratio	Thickness	Surface Dose	Relative Increase to Thermoplast
Thermoplastic	-	0.5 cm	80.58%	-
Silicone Rubber	-	0.5 cm	82.18%	1.99%
	-	1.0 cm	95.23%	18.18%
	-	1.5 cm	96.52%	19.78%
Glycerol–gelatin	1:3	0.5 cm	85.18%	5.71%
		1.0 cm	97.98%	21.59%
		1.5 cm	99.87%	23.94%
	2:3	0.5 cm	88.77%	10.16%
		1.0 cm	98.27%	21.95%
		1.5 cm	99.88%	23.95%
Aloe vera gel–gelatin	1:3	0.5 cm	86.15%	6.91%
		1.0 cm	95.10%	18.02%
		1.5 cm	99.08%	22.96%
	2:3	0.5 cm	87.23%	8.25%
		1.0 cm	96.35%	19.57%
		1.5 cm	99.73%	23.77%



Based on Table 14, all developed boluses increased the surface dose by 1.99%–23.95% compared with the 0.5 cm thermoplast bolus. Increasing the bolus thickness from 0.5 cm to 1.0 cm and 1.5 cm resulted in surface doses ranging from 95.10% to 98.27% and 96.52% to 99.88%, respectively. Although the 1.5 cm thickness produced the highest surface dose, the additional increase compared with the 1.0 cm thickness was relatively small for some materials, indicating a tendency toward a surface dose plateau.

Selecting the optimal bolus thickness requires balancing surface dose enhancement with Relative Electron Density (RED). Based on these two parameters, the 0.5 cm silicone rubber bolus was considered a potential option because its RED value of 0.99184 was close to that of breast tissue, with a surface dose of 82.18%. The glycerol-gelatin bolus with a 2:3 composition ratio and a thickness of 1.0 cm demonstrated a balance between RED (0.99172) and surface dose (98.27%). Meanwhile, the aloe vera-gelatin bolus with a 1:3 composition ratio and a thickness of 1.5 cm exhibited a RED value of 1.04230, approaching that of muscle tissue, and a surface dose of 99.08%.

These findings are consistent with previous studies by Kong et al. [8], Hariyanto et al. [14], and Muslimah Putri Utami et al. [15], which demonstrated that bolus application and increased thickness can enhance the surface dose of 6 MV photon beams by shifting the dose build-up region closer to the skin surface. The glycerol-gelatin and aloe vera-gelatin formulations therefore show potential as alternative bolus materials, while silicone rubber remains a potential option depending on its RED characteristics at the selected thickness.

Overall, a bolus thickness of 1.5 cm produced the highest surface dose among the evaluated thicknesses. However, the most suitable bolus cannot be determined from surface dose alone. RED, material homogeneity, expert validation, physical stability, and practical applicability must also be considered collectively. Furthermore, a surface dose approaching 100% indicates improved surface dose coverage and a reduction in the skin-sparing effect; it does not, by itself, establish whether the delivered dose is excessive or clinically appropriate.

3. Compliance of Dosimetry Testing with IAEA TRS-398 Principles

Dosimetry testing refers to the IAEA TRS-398a principle through the use of a Markus chamber as an ionization detector and a solid water phantom as a measurement medium. The irradiation parameters were made uniform, namely 6 MV photons, SSD 100 cm, and a field area of 10 × 10 cm². Each measurement was performed three times to obtain the average value and standard deviation as an indicator of the consistency of the results. However, the application of TRS-398a is limited to the principle of comparative measurement of surface doses, not the determination of absolute water absorbed doses, because it does not include all protocol corrections, such as calibration factors, beam quality, polarity, and ion recombination.

4. Recommendations on Image Quality and Radiation Safety Based on Surface Dose Results

The dosimetric test results demonstrated that all developed boluses increased the surface dose compared with the conditions without a bolus and with thermoplast. These findings are consistent with Kong et al. [8], who described the role of bolus materials in increasing superficial tissue dose and improving target dose coverage. In addition, the stability of CT Number and Relative Electron Density (RED) is important for supporting the accuracy of radiotherapy treatment planning. Substantial variations in Hounsfield Unit (HU) values may indicate material inhomogeneity, potentially affecting image interpretation and dose calculation accuracy [12].

The glycerol-gelatin bolus with a 2:3 composition ratio and a thickness of 1.5 cm produced the highest surface dose of 99.88%. However, the highest surface dose does not necessarily indicate the most appropriate formulation, as potential skin reactions and material homogeneity must also be considered [16], [17]. The aloe vera-gelatin bolus with a 1:3 composition ratio and a thickness of 1.5 cm represents a potential alternative based on the combined consideration of RED, surface dose, and homogeneity characteristics. Before clinical application, further investigations are necessary to evaluate CT Number and RED stability, image artifacts, material homogeneity, air gaps, and dose distribution through verification using a Treatment Planning System (TPS). These assessments are essential to establish dosimetric accuracy and support patient safety.

5. Surface Dose Interpretation in the Context of Post-Mastectomy Breast Radiotherapy

The use of bolus materials in post-mastectomy breast radiotherapy (PMRT) aims to increase the surface dose by reducing the skin-sparing effect and improving dose coverage in superficial tissues [18]. However, bolus application requires patient-specific consideration because international practices are not uniformly standardized, and clinical guidelines recommend its use for specific indications rather than routinely for all patients [19], [16].

The results demonstrated that the surface dose increased from 16.02% under the condition without a bolus to 80.58% with thermoplast and 82.18%–99.88% with the developed boluses. Nevertheless, dose

enhancement must be balanced against potential skin toxicity, bolus thickness, and dose homogeneity [18]. The glycerol-gelatin bolus with a 2:3 composition ratio and a thickness of 1.5 cm produced the highest surface dose of 99.88%. Meanwhile, the aloe vera-gelatin bolus with a 1:3 composition ratio and the same thickness demonstrated potential as an alternative, with a surface dose of 99.08% and a RED value of 1.0423. However, further investigations involving Treatment Planning System (TPS) evaluation, dosimetric verification, air gap analysis, and material safety assessment are necessary before clinical application.

6. Performance Comparison Between Materials at the Same Thickness

Table 15. Comparison of RED and Surface Dose Between Materials at the Same Thickness

Thickness	Bolus Material	Ratio	RED	Surface Dose
0.5 cm	*Silicone Rubber*	-	0.99184	82.18%
0.5 cm	Glycerol–gelatin	1:3	0.92442	85.18%
0.5 cm	Glycerol–gelatin	2:3	0.99122	88.77%
0.5 cm	Aloe vera gel–gelatin	1:3	0.96296	86.15%
0.5 cm	Aloe vera gel–gelatin	2:3	0.96152	87.23%
1.0 cm	*Silicone Rubber*	-	1.11809	95.23%
1.0 cm	Glycerol–gelatin	1:3	1.03254	97.98%
1.0 cm	Glycerol–gelatin	2:3	0.99172	98.27%
1.0 cm	Aloe vera gel–gelatin	1:3	0.98152	95.10%
1.0 cm	Aloe vera gel–gelatin	2:3	0.96536	96.35%
1.5 cm	*Silicone Rubber*	-	1,17327	96.52%
1.5 cm	Glycerol–gelatin	1:3	1.09868	99.87%
1.5 cm	Glycerol–gelatin	2:3	1,10696	99.88%
1.5 cm	Aloe vera gel–gelatin	1:3	1.0423	99.08%
1.5 cm	Aloe vera gel–gelatin	2:3	1.03694	99.73%

The results showed that all developed boluses produced higher surface doses compared to thermoplast as a clinical comparator. At a thickness of 0.5 cm, the glycerol–gelatin ratio of 2:3 produced the highest surface dose of 88.77% with a RED of 0.99122. At a thickness of 1.0 cm, the same material again showed the highest performance, namely 98.27% with a RED of 0.99172. Meanwhile, at a thickness of 1.5 cm, the glycerol–gelatin ratio of 2:3 produced the highest surface dose of 99.88%, followed by the glycerol–gelatin ratio of 1:3 at 99.87%. These results indicate that increasing material thickness and composition affect the dosimetric performance of the bolus.

Aloe vera gel–gelatin material also showed good potential. At 1.0 cm thickness, a 1:3 ratio had a RED of 0.98152, which is close to that of breast tissue, with a surface dose of 95.10%. At 1.5 cm thickness, ratios of 2:3 and 1:3 produced surface doses of 99.73% and 99.08%, respectively. These findings support the potential of gel-based materials as bolus alternatives, in line with studies by Oliveira et al. on boluses made from water, glycerin, and gelatin and Kong et al. on the use of hydrogels and silica gel to increase superficial dose coverage.

Silicone Rubber also has the potential to be used as a bolus material, with a RED value at 1.0 cm thickness of 1.11809, which is close to the results of the study by Fajriani et al. However, its surface dose tends to be lower than gelatin-based materials at the same thickness. Overall, glycerol–gelatin ratio 2:3 excels in increasing the surface dose, while aloe vera–gelatin gel offers a balance between RED values close to soft tissue and high surface dose. Therefore, bolus selection needs to consider the surface dose, RED, homogeneity, shape stability, and ease of use, not just one dosimetric parameter.

Bolus homogeneity based on thickness variation

Bolus homogeneity was evaluated by examining the uniformity of CT Number values across five regions of interest (ROIs). The measurement results indicated that a thickness of 1.5 cm tended to produce more uniform CT Number values than thicknesses of 0.5 and 1.0 cm, particularly for silicone rubber, glycerol-gelatin, and aloe vera-gelatin boluses. These findings suggest that material thickness and composition may influence bolus homogeneity. This observation is consistent with Oliveira et al. [7], who emphasized the importance of uniform Hounsfield Unit (HU) values and air bubble control in gelatin-based bolus fabrication, and Liang et al. [21], who reported that composition can influence gel structural stability. Unlike the findings reported by Muslimah Putri Utami et al. [15], the present study indicated a tendency for thickness variations

to influence homogeneity. However, these findings remain descriptive because the assessment was based on five ROI measurements. Further research should incorporate quantitative indicators, such as standard deviation and coefficient of variation, to provide a more robust assessment of material homogeneity.

Feasibility of boluses as radiotherapy boluses

Bolus suitability was assessed based on Relative Electron Density (RED) values, a 6 MV photon surface dose, material homogeneity, and expert validation. Measurement results showed that RED suitability varied depending on material type, composition ratio, and thickness. Although thermoplast has a RED of 0.77186, this material is still used as a clinical comparator because it is a routine bolus in research facilities.

All developed boluses were able to increase the surface dose compared to the condition without bolus by 16.02% and 0.5 cm thermoplast by 80.58%. The surface dose of the developed bolus reached 82.18%–88.77% at a thickness of 0.5 cm, 95.10%–98.27% at a thickness of 1.0 cm, and 96.52%–99.88% at a thickness of 1.5 cm. In terms of homogeneity, the 1.5 cm thickness tends to show a more uniform CT Number value, although further quantitative analysis is still needed. Expert validation also showed that all materials were included in the very feasible category, namely Silicone Rubber at 88.49%, glycerol–gelatin at 86.51%, and aloe vera gel–gelatin at 86.11%. Thus, all three materials have the potential to be developed as radiotherapy boluses, but further dosimetry and homogeneity testing are still needed before clinical application.

Table 16. Summary of Best Candidates Based on Bolus Material Type

Material Group	Best Candidate Based on Parameters	RED	Surface dose	Information
Silicone Rubber	*Silicone Rubber*0.5 cm	0.99184	82.18%	RED is closest to breast tissue and the surface dose is higher than 0.5 cm thermoplast.
Glycerol-gelatin	Glycerol–gelatin ratio 2:3 thickness 1.0 cm	0.99172	98.27%	RED approaches breast tissue and the surface dose is already high approaching dmax
Aloe vera gel-gelatin	Aloe vera gel–gelatin ratio 1:3, thickness 1.5 cm	1.04230	99.08%	RED is closest to muscle tissue, high surface dose, and good homogeneity tendency

The best bolus candidates were determined based on the balance of RED value, surface dose, homogeneity, expert validation, and applicability aspects. The best candidates in each group were Silicone Rubber 0.5 cm, glycerol–gelatin ratio 2:3 thickness 1.0 cm, and aloe vera gel–gelatin ratio 1:3 thickness 1.5 cm. Overall, aloe vera gel–gelatin ratio 1:3 thickness 1.5 cm was considered the most optimal because it had RED 1.04230 which was close to muscle tissue, surface dose 99.08%, and good homogeneity tendency. Meanwhile, glycerol–gelatin ratio 2:3 thickness 1.5 cm produced the highest surface dose of 99.88%, but was not the most optimal candidate when all parameters were considered.

The feasibility of the bolus is still limited to physical testing using a CT simulator, dosimetry testing with a LINAC and Markus chamber on a solid water phantom, and expert validation. Therefore, clinical application requires further research including dose distribution analysis in the TPS, long-term stability, air gap evaluation, and patient safety and comfort.

Applicative Comparison Between Bolus Materials

In addition to the RED, surface dose, homogeneity, and expert validation aspects, the developed bolus was also evaluated based on manufacturing costs, ease of manufacture, setting time, shape durability, hygiene, and potential duration of use. The cost was calculated based on the price of the materials, namely Silicone Rubber and catalyst Rp217/gram, glycerol Rp56/mL, aloe vera gel Rp148/gram, propylene glycol Rp48/gram, and gelatin Rp240/gram. The calculation was carried out for a 10 × 10 cm bolus with thickness variations of 0.5 cm, 1.0 cm, and 1.5 cm.

Table 17. Bolus Manufacturing Cost Estimate Based on Material and Thickness

Material	Ratio	0.5 cm	1 cm	1.5 cm
Silicone Rubber	-	Rp10,850	Rp21,700	Rp. 32,550
Glycerol- Gelatin	1:3	Rp7,875	Rp. 15,750	Rp23,625

	2:3	Rp6,840	Rp13,680	Rp20,520
Aloe Vera Gel – Gelatin	1:3	Rp8,738	Rp17,475	Rp26,213
	2:3	Rp8,220	Rp16,440	Rp24,660

Information: The cost estimate is based on the price of the materials used in the study and the estimated material requirements for a 10 × 10 cm bolus. This calculation does not include other operational costs such as electricity, printing equipment, plastic wrap, and labor.

Based on Table 16, Silicone Rubber has the highest manufacturing cost, but excels in shape retention and material stability. In contrast, glycerol–gelatin ratio 2:3 is the most economical material, with costs of Rp6,840, Rp13,680, and Rp20,520 for thicknesses of 0.5 cm, 1.0 cm, and 1.5 cm, respectively. This material also produces the highest surface dose at 1.5 cm thickness, but requires clean and closed storage to maintain hygiene and shape stability. Meanwhile, aloe vera gel–gelatin ratio 1:3 at 1.5 cm thickness shows a balance between RED value and surface dose, thus potentially being an optimal alternative based on dosimetry and applicability aspects.

Table 18. Applicative Comparison Between Bolus Materials

Aspect	*Silicone Rubber*	Glycerol–gelatin	Aloe vera gel–gelatin
Manufacturing costs	The tallest	Most economical	Economical
Ways of making	It's relatively simple, namely mixing Silicone Rubber with a catalyst and then molding it.	Requires heating gelatin, mixing glycerol, propylene glycol, then molding	Requires heating gelatin, mixing aloe vera gel, propylene glycol, then molding
Setting time	Following the material curing process	±30–60 minutes until hardened	±30–60 minutes until hardened
Form resistance	Most stable	Quite stable with closed storage	Quite stable with closed storage
Hygiene	Easier to maintain because it is not water based	It needs to be wrapped and stored closed	It needs to be wrapped and stored closed
Duration of use	Potentially longer due to better shape stability	Based on visual observation during storage, the shape is still relatively stable, but further stability testing is needed.	Based on visual observation during storage, the shape is still relatively stable, but further stability testing is needed.
Main advantages	Shape stability and material durability	Low cost and high surface dose	RED balance and surface dose

Based on Table 18, each bolus material demonstrated distinct advantages and limitations. Silicone rubber exhibited superior durability and shape stability but had the highest manufacturing cost. Glycerol-gelatin was more economical and produced the highest surface dose at a composition ratio of 2:3 and a thickness of 1.5 cm. Meanwhile, aloe vera-gelatin with a 1:3 composition ratio and a thickness of 1.5 cm demonstrated a potential balance between physical characteristics and dosimetric performance. These findings are consistent with previous investigations into the development of gelatin-based and hydrogel-based bolus materials [7], [8].

From a hygiene perspective, gelatin-based materials require particular attention because their water content and water activity can influence physical stability and microbial growth [22]. Equipment that comes into contact with intact skin is classified as noncritical but still requires appropriate routine cleaning and disinfection to minimize the risk of cross-contamination [23]. Since microbiological safety was not evaluated in this study, repeated use of the developed gel-based boluses cannot be recommended without further testing. Silicone rubber may offer advantages in physical stability and maintenance; however, appropriate cleaning and disinfection procedures remain necessary.

Overall, the glycerol-gelatin bolus with a 2:3 composition ratio and a thickness of 1.5 cm was the most advantageous in terms of manufacturing cost and surface dose enhancement. Meanwhile, the aloe vera-gelatin bolus with a 1:3 composition ratio and a thickness of 1.5 cm represents a potential alternative based on the balance of its physical and dosimetric characteristics. Nevertheless, selecting the most suitable material requires comprehensive consideration of RED, homogeneity, durability, hygiene, and expert validation before any clinical application.

Conclusion

This study shows that bolus materials made from silicone rubber, glycerol-gelatin, and aloe vera-gelatin gel have different physical, dosimetric, and applicative characteristics, thus potentially being used as alternative bolus materials in post-mastectomy breast cancer radiotherapy. Silicone rubber has advantages in durability and shape stability, but requires a relatively high manufacturing cost. In contrast, glycerol-gelatin offers cost efficiency and increased surface dose, especially at a composition ratio of 2:3 with a thickness of 1.5 cm. Aloe vera-gelatin gel also shows potential as an alternative material, although its use requires considering the balance between physical characteristics and dosimetric performance. Differences in relative electron density (RED) values, surface dose, homogeneity, and applicative characteristics emphasize that bolus selection needs to be tailored to clinical needs and irradiation conditions. However, the results of this study have limitations because the testing is still focused on material characteristics and dosimetric evaluation under certain measurement conditions. Therefore, the results obtained cannot fully describe the performance of the bolus in clinical use in patients, including the influence of anatomical variations, surface conformity, and position changes during irradiation.

Practically, the results of this study can serve as a basis for consideration for medical physicists and radiotherapists in selecting and developing appropriate bolus materials based on surface dose requirements, form stability, ease of manufacture, hygiene, and cost. Glycerol-gelatin can be considered an economical alternative, while silicone rubber has the potential to be used when durability and form stability are priorities. However, the clinical application of each material must be preceded by adequate dosimetric testing and validation in accordance with radiotherapy safety protocols. Future research is recommended to expand testing to include variations in composition and thickness, evaluate dose uniformity and the effect of the air gap between the bolus and the skin surface, and conduct repeated testing to assess the reproducibility of the results. Furthermore, testing for durability, stability during storage, material safety, and dosimetric evaluation under conditions closer to clinical practice is necessary. Thus, the development of bolus materials can produce alternatives that are not only economical and easy to apply, but also meet dosimetric and safety requirements before being recommended for wider clinical use.

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