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Original Research

Comparison of Play Dough and Bread Dough with Ballistic Gel as Soft Tissue Simulator: An Ex-Vivo Study with Sheep's Head as the Gold Standard

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ABSTRACT

Objective: This study aims to test the usability of bread dough, play dough, and ballistic gel in soft tissue simulations by comparing them with a sheep's head as the gold standard. Cone beam computed tomography (CBCT) images of the sheep's head was obtained as the gold standard.

Methods: The sheep's head was re-covered with ballistic gel, play dough, and bread dough, respectively. Two different CBCT images (protocol A- FOV: 8x15cm, 90kVp, 6.3mA, 4.5s, 0.35mm-voxel size, 574 mGy cm^2; protocol B- FOV: 13x15cm, 90kVp, 5mA, 8.1s, 0.30mm-voxel size, 823 mGy cm^2) were obtained from the gold standard and each simulation model. The Hounsfield unit (HU) feature in the software of the CBCT was used to evaluate gray values. Pearson Correlation Coefficient was used to examine the relationship between variables that comply with normal distribution, and Spearman's rho Correlation Coefficient was used to examine the relationship between variables that do not comply with normal distribution. The significance level was taken as $p < 0.05$.

Results The highest positively significant correlation with the gold standard in the mandible was with bread dough ($r = 0.944$, $p < 0.001$), while in the maxilla it was with play dough ($r = 0.879$, $p < 0.001$). The highest positive significant correlation with the gold standard in gray values selected from teeth and bone was with ballistic gel ($r = 0.762$, $p=0.004$; $r = 0.638$, $p=0.008$, respectively), while in pulp it was with play dough ($r = 0.874$, $p < 0.001$). A very high, positive, and significant correlation was found between protocols A and B of all simulation models. The highest positive significant correlation of the gold standard protocol A was found with the ballistic gel simulation protocol B ($r = 0.893$, $p < 0.001$).

Conclusion: Play-dough can be an alternative soft tissue simulator to ballistic gel, especially in ex vivo studies on pulp morphology.

Keywords cone beam computed tomography, hounsfield units, play dough, pulp volume, soft tissue simulation

INTRODUCTION

Cone beam computed tomography (CBCT) has become an alternative to conventional multidetector CT in dentistry due to its reduction in radiation dose and its contribution to diagnostic accuracy with the high resolution it provides [1]. The current consensus that the artifacts encountered in CBCT images and the gray scales obtained are not exact physical equivalents of the materials necessitates studies in which new software and technologies are tested in order to develop CBCT algorithms [2,3].

Due to the clinical ethics rules and harmful effects of ionizing radiation, prospective CBCT studies must be performed in vitro or ex vivo [4,5]. In studies aiming to increase CBCT image quality and improve diagnostic accuracy, projection methods are tested by changing various parameters (such as mA, kVp, scanning time) [3,6]. Organic materials (such as a skull or mandible) used in ex vivo studies to evaluate CBCT image quality are coated with materials that can serve as soft tissue simulators in order to simulate vital tissues realistically [4,7].

Today, the most commonly used soft tissue simulators in dentomaxillofacial radiology studies are ice, wax, and acrylic [5-8]. However, ballistic gel has recently begun to be used as an alternative to these materials, which have limitations affecting image quality in soft tissue simulation [5]. It has been shown that ballistic gel prepared in accordance with the manufacturer's instructions is quite successful in soft tissue simulation compared to other materials [5]. However, the limited accessibility of ballistic gel compared to acrylic and wax for dentists can be considered a disadvantage. Since ballistic gel is sensitive to thermal change, it is acceptable that the most important disadvantage of ballistic gel is that the manipulation time is shorter than wax and acrylic [9].

Flour, water, and salt, which are the main ingredients in bread dough and play dough, contain dense carbon (C), oxygen (O), and hydrogen (H) atoms and are similar to organic components, especially soft tissue, in terms of chemical structure [10-13]. In addition, play-dough was found to be usable as a bolus material in radiotherapy [12]. This suggests that the radiological properties of play-dough may also be suitable for soft tissue simulation. Unlike bread dough, play dough contains coloring, hardening, and lubricating additives to make it suitable for children's manipulation and educational activities [11,14].

This study aims to test the usability of bread dough, play dough, and ballistic gel in soft tissue simulations by comparing them with the gold standard.

Main Points

- Play dough can be an alternative for soft tissue simulation in CBCT imaging.
- Ballistic gel is one of the most suitable materials for ex-vivo CBCT imaging of alveolar bone.
- Bread dough can have the disadvantage of being homogeneously prepared.
- Play dough may be a more suitable soft tissue simulation material than ballistic gel, especially for ex-vivo pulp imaging.

MATERIALS AND METHODS

Ethics committee approval was received for this study from Karamanoglu Mehmetbey University Faculty of Medicine Clinical Research Ethics Committee (Desicion number: 02-2024/8, Date: 2024-03-12).

Sample Preparation

Fresh sheep head obtained from a commercial slaughterhouse was coated with C-silicone impression material (Zetaplus, Zhermack, Dentsply). 30 minutes after the polymerization was completed, the impression was carefully cut in half horizontally, and the contact fit of the parts was maintained. First, a CBCT image of the sheep's head was obtained as the gold standard. Then, all superficial soft tissues, including the skin and muscles in the head region, were removed with sharp tools such as knives without applying any chemicals in order not to affect the bone density and structure. The sheep's head was re-covered with ballistic gel, play dough, and bread dough, respectively. Each coating was wrapped with transparent foil to prevent different simulation materials from interacting with each other and the impression material. During the manipulation process, the sheep head covered with the simulator and wrapped with foil was placed back into the impression material, whose two parts were brought to their original position, and the original form was given with a soft tissue simulator (Figure 1). CBCT images were obtained for each simulation model in the same way as the gold standard exposure protocol.

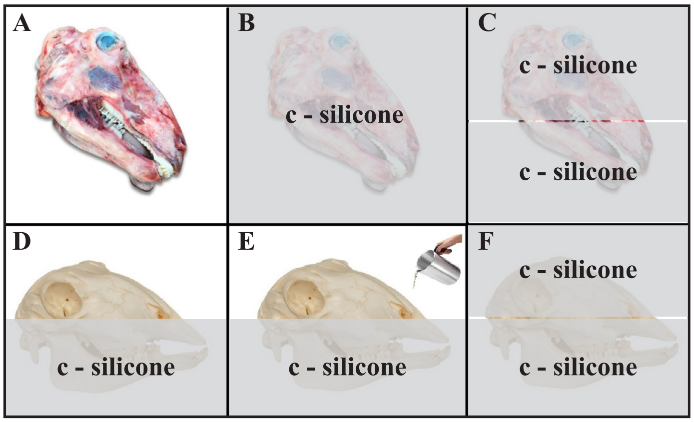

Figure 1. Schematic representation of sample preparation, Fresh sheep head (A), Fresh sheep head coated with C-silicone (B), C-silicone mold cut in half horizontally (C), Placement fresh sheep head removed skin and muscles into a half mold (D), Adding an appropriate amount of simulation material to both half molds (E), Positioning both mold parts to their prior positions (F)

Preparation of Simulation Materials

Ballistic gel was obtained by using the preparation method preferred in a previous study and the commercial product (Gelatin, Dr Oetker) [15]. An easily accessible commercial product (Play-Doh, Hasbro Inc., Rhode Island, USA) was chosen for the Play-Doh simulation. A recipe in the literature was used to prepare the bread dough for simulation [10]. A homogeneous dough was obtained by adding 350ml of water to 500g of flour at a temperature of approximately 25°C and mixing manually for 1 hour and then resting for approximately 3 hours at a temperature of 2-6°C.

CBCT Scanning Protocol

Two different (protocol A- FOV: 8x15cm, 90kVp, 6.3mA, 4.5s, 0.35mm-voxel size, 574 mGy cm^2; protocol B- FOV: 13x15cm, 90kVp, 5mA, 8.1s, 0.30mm-voxel size, 823 mGy cm^2) CBCT (Kavo OP 3D PRO, Biberach, Germany) images were obtained from the gold standard and each simulation model. The sheep's head was placed in the ideal exposure position with the head-neck support equipment of the CBCT (Figure 2).

Image Evaluation and Data Analysis

Two observers (TC, 7 years of experience in oral radiology; SS, 6 years of experience in oral radiology) worked together to identify the region of interest (ROI)s to be analyzed and reached consensus on each ROI. Hounsfield units (HU) feature in the software of the CBCT, which was used to evaluate gray values. HU feature in the CBCT software provides HU-like values based on grayscale data, rather than the absolute HU values obtained from conventional CT. The same ROIs (2x2 pixels for each localization) were used in each CBCT image to provide a standardized evaluation of the gray values of teeth, pulp, alveolar bone, and soft tissues for the gold standard and simulation models. Coronal sections were used to evaluate the gray values of the teeth, pulp, and soft tissues in the mandibular anterior region. The reason for this is that sheep mandibular anterior teeth are morphologically positioned parallel to the horizontal plane [16]. Therefore, the tooth and pulp tissue can be observed more clearly in the coronal section (Figure 3). For the analysis of the alveolar bone gray value in the mandibular anterior, the region close to the mid-suture in the mandibular anterior was selected and analyzed in axial section (Figure 4). Tooth and pulp gray values were taken from the same molar in the maxillary and mandibular posterior regions. The soft tissue gray value was analyzed from the buccal area of the selected molar. Axial sections were used in posterior CBCT image analysis (Figure 5). Trabecular bone in the bifurcation region of the selected molar tooth was used to analyze the posterior alveolar bone gray value (Figure 6). Since there are no teeth in the maxillary anterior region of sheep, tooth and pulp data could not be obtained from this region [16]. Statistical analysis of all gray values obtained, except for maxillary anterior tooth and pulp data, was performed with protocol A-B, maxilla-mandible, anterior-posterior, and right-left subheadings.

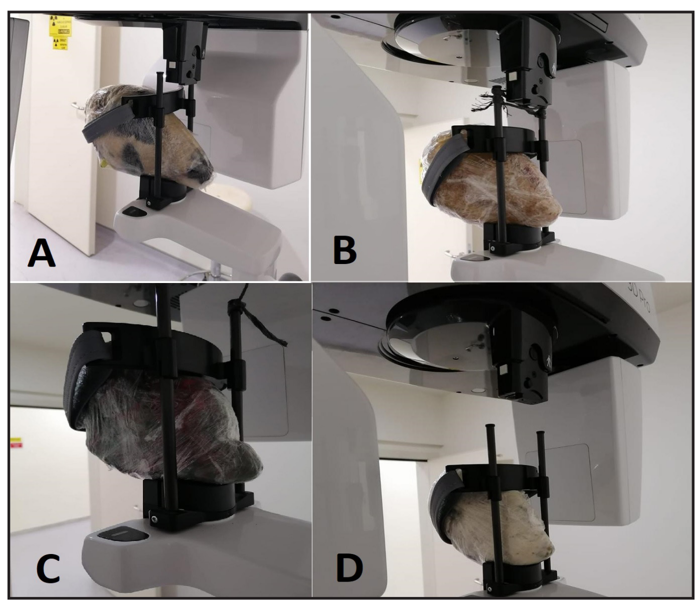

Figure 2. Positioning of sheep's head in CBCT with gold standard (A), ballistic gel (B), play dough (C), and bread dough (D) simulation

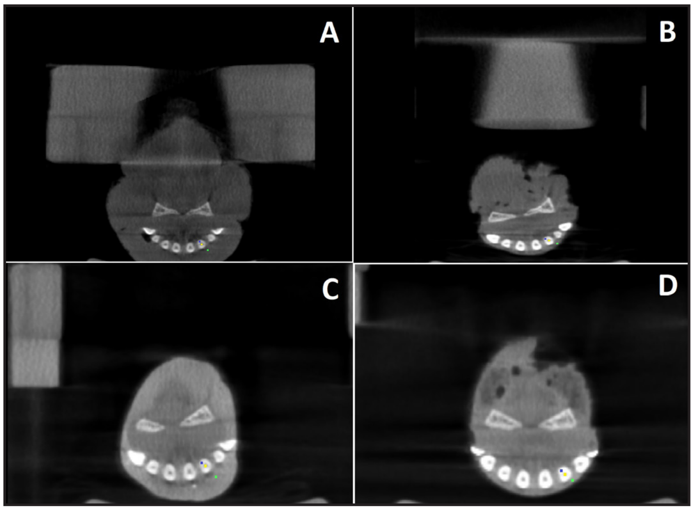

Figure 3. ROIs selected from teeth (blue), pulp (yellow), and soft tissue (green) in the anterior mandible on gold standard (A), ballistic gel (B), play dough (C), and bread dough (D) simulations

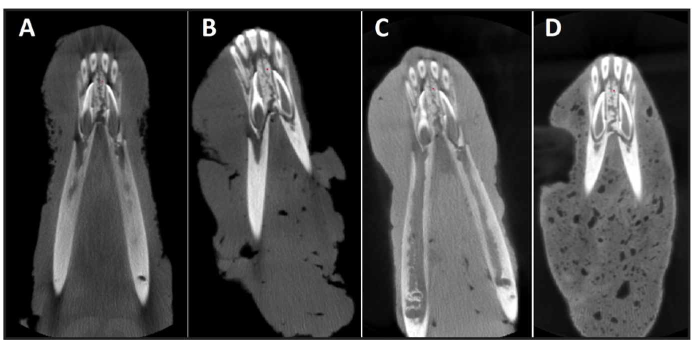

Figure 4. ROIs selected from alveolar bone (red) in the anterior mandible on gold standard (A), ballistic gel (B), play dough (C), and bread dough (D) simulations

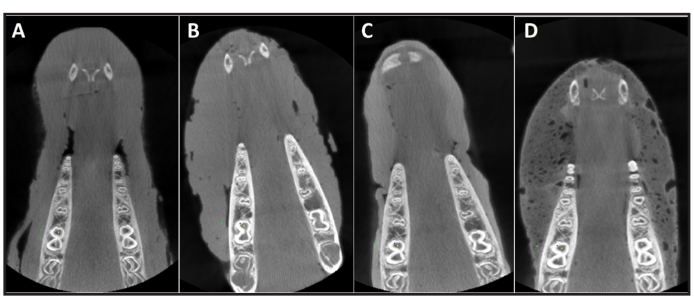

Figure 5. ROIs selected from teeth (blue), pulp (yellow), and soft tissue (green) in the posterior maxilla on gold standard (A), ballistic gel (B), play dough (C), and bread dough (D) simulations

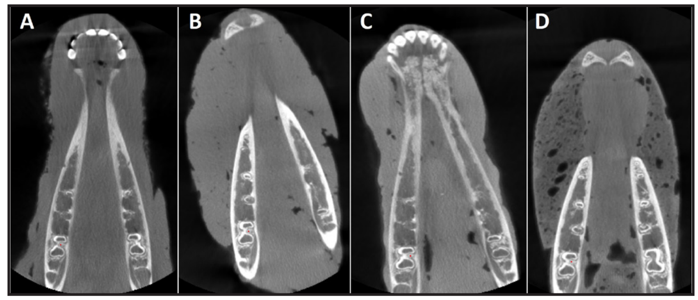

Figure 6. ROIs selected from alveolar bone (red) in the posterior mandible on gold standard (A), ballistic gel (B), play dough (C), and bread dough (D) simulations

Statistical Analysis

Data were analyzed with IBM SPSS V23. Compliance with normal distribution was examined with the Shapiro-Wilk and Kolmogorov-Smirnov Tests. Independent Samples t Test was used to compare data with normal distribution according to binary groups, and the Mann-Whitney U Test was used to compare data that did not comply with normal distribution. Kruskal-Wallis Test was used to compare data that did not comply with normal distribution in groups of three or more, and multiple comparisons were made with the Dunn Test. Pearson Correlation Coefficient was used to examine the relationship between variables that comply with normal distribution, and Spearman's rho Correlation Coefficient was used to examine the relationship between variables that do not comply with normal distribution. Analysis results were presented as mean ± standard deviation and median (minimum–maximum). The significance level was taken as $p < 0.05$.

RESULTS

Among soft tissue simulators, bread dough and play dough were found to be more consistent with the gold standard data for the jaw and location. Gray scale values for teeth and alveolar bone indicate that ballistic gel is a more suitable simulator for hard tissue. However, evaluation of gray scale values for soft tissue and pulp revealed that play dough was the most consistent simulation material with the gold standard.

Gray values (in Hounsfield unit) obtained from the gold standard and simulation models are shown in Table 1. Correlations with the gold standard according to jaw, side, localization, and selected tissues are shown in Table 2. The highest positively significant correlation with the gold standard in the mandible was with bread dough ($r = 0.944$, $p < 0.001$), while in the maxilla it was with play dough ($r = 0.879$, $p < 0.001$). The highest positive significant correlation with the gold standard in the anterior region was with bread dough ($r = 0.934$, $p < 0.001$), while in the posterior region it was with play dough ($r = 0.897$, $p < 0.001$). The highest positive significant correlation with the gold standard in gray values selected from teeth and bone was with ballistic gel ($r = 0.762$, $p=0.004$; $r = 0.638$, $p=0.008$, respectively), while in pulp and soft tissue it was with play dough ($r = 0.874$, $p < 0.001$; $r = 0.268$, $p=0.316$, respectively). In the evaluation made without any discrimination, the highest positive significant correlation with the gold standard is with play-dough ($r = 0.923$, $p < 0.001$). While there was a high or very high positive significant correlation with the gold standard for all simulation models in the gray values selected from teeth, pulp, and bone, a low level positive correlation was found with the gold standard in the gray values selected from soft tissue for all simulation models (Table 2).

The comparison of the mean and median data of the gray values according to the jaws is shown in Table 3. No significant difference was found between the medians of the gold standard maxilla and mandible gray values ($p = 0.084$). A significant difference was found between the maxilla and mandible gray values of ballistic gel, play dough, and bread dough ($p=0.003$, $p=0.008$, $p=0.003$, respectively). Additionally, in all simulation models, gray values in the mandible were found to be higher than in the maxilla.

The comparison of gray values obtained from simulation models between the right and left is shown in Table 4. No significant difference was found between the sides in the gold standard and all simulation models ($p=0.712$-0.989).

The comparison of the mean and median data of the gray values obtained according to localization is shown in Table 5.

Table 1. Gray values (in Hounsfield unit) obtained from all models

		Right								Left							
		Anterior				Posterior				Anterior				Posterior			
Protocol A		Tooth	Pulp	Bone	Soft tissue	Tooth	Pulp	Bone	Soft tissue	Tooth	Pulp	Bone	Soft tissue	Tooth	Pulp	Bone	Soft tissue
Mandible	GOLD	1038	430	795	38	908	31	492	163	1035	401	877	-111	1053	-6	686	102
	BGEL	1419	733	1084	104	935	87	892	119	1547	833	1035	80	853	121	756	57
	PDOH	1043	601	797	126	691	83	774	285	1156	542	881	97	753	67	776	330
	BDOH	1402	661	924	146	1080	175	879	185	1408	756	907	133	974	145	873	183
Maxilla	GOLD			550	105	717	-112	788	-11			542	70	532	-78	791	31
	BGEL			718	94	724	70	762	90			678	75	657	38	656	8
	PDOH			592	101	730	-65	520	293			575	117	630	-28	590	165
	BDOH			674	157	890	24	642	-112			659	145	812	-7	724	-140
Protocol B		Tooth	Pulp	Bone	Soft tissue	Tooth	Pulp	Bone	Soft tissue	Tooth	Pulp	Bone	Soft tissue	Tooth	Pulp	Bone	Soft tissue
Mandible	GOLD	981	557	920	17	954	-102	760	223	931	580	938	-5	955	-191	647	286
	BGEL	1421	800	1038	123	851	75	826	130	1380	738	1081	119	909	95	668	103
	PDOH	1110	789	857	235	1020	-32	877	272	1215	594	811	285	1033	39	797	351
	BDOH	1389	868	999	164	1168	85	872	143	1393	828	951	159	1120	137	781	138
Maxilla	GOLD			676	55	803	-125	636	60			628	52	854	-58	537	70
	BGEL			449	121	783	-13	451	68			418	179	803	110	435	82
	PDOH			635	331	691	-87	408	342			592	314	721	23	354	276
	BDOH			763	177	789	88	526	-166			649	191	882	106	491	-114

GOLD: Gold standard, BGEL: Ballistic gel, PDOH: Play dough, BDOH: Bread dough

Table 2. Correlation of the relationship between original values and simulation values with distinction (jaw, side, location and selected tissue) and without distinction (total)

GOLD				
Jaw	Mandible	BGEL	0.887**	**<0.001**
		PDOH	0.910**	**<0.001**
		BDOH	0.944**	**<0.001**
	Maxilla	BGEL	0.874**	**<0.001**
		PDOH	0.879**	**<0.001**
		BDOH	0.816**	**<0.001**
Side	Right	BGEL	0.911**	**<0.001**
		PDOH	0.905**	**<0.001**
		BDOH	0.909**	**<0.001**
	Left	BGEL	0.863**	**<0.001**
		PDOH	0.945**	**<0.001**
		BDOH	0.914**	**<0.001**
Location	Anterior	BGEL	0.890**	**<0.001**
		PDOH	0.931**	**<0.001**
		BDOH	0.934**	**<0.001**
	Posterior	BGEL	0.870**	**<0.001**
		PDOH	0.897**	**<0.001**
		BDOH	0.865**	**<0.001**
Selected tissue	Tooth	BGEL	0.762**	**0.004**
		PDOH	0.641*	**0.025**
		BDOH	0.705*	**0.010**
	Pulp	BGEL	0.790**	**0.002**
		PDOH	0.874**	**<0.001**
		BDOH	0.818**	**0.001**
	Bone	BGEL	0.638*	**0.008**
		PDOH	0.535*	**0.033**
		BDOH	0.621*	**0.010**
	Soft tissue	BGEL	0.175*	0.517
		PDOH	0.268**	0.316
		BDOH	0.152**	0.575
Total		BGEL	0.887**	**<0.001**
		PDOH	0.923**	**<0.001**
		BDOH	0.913**	**<0.001**

*Pearson Correlation Coefficient; **Spearman's rho Correlation Coefficient; GOLD: Gold standard; BGEL: Ballistic gel; PDOH: Play dough; BDOH: Bread dough

Table 3. Comparison of gold standard and simulation models values according to jaws

Soft Tissue Type	Jaw				Test Statistics	p
	Mandible		Maxilla			
	Mean ± S.D.	Median (min-max)	Mean ± S.D.	Median (min-max)		
GOLD	511.97 ± 417.55	568.5 (-191 - 1053)	338.04 ± 354.15	318.5 (-125 - 854)	279.5	0.084*
BGEL	656.63 ± 482.53	778 (57 - 1547)	352.33 ± 301.36	298.5 (-13 - 803)	203	**0.003***
PDOH	601.72 ± 372.47	722 (-32 - 1215)	367.5 ± 262.28	348 (-87 - 730)	2.76	**0.008****
BDOH	688.31 ± 461.35	848 (85 - 1408)	368.75 ± 369.5	341 (-166 - 890)	206.5	**0.003***

*Mann Whitney U Test; ** Independent Samples t Test; GOLD: Gold standard; BGEL: Ballistic gel; PDOH: Play dough; BDOH: Bread dough

Table 4. Comparison of gold standard and simulation models values according to sides

Soft Tissue Type	Side				Test Statistics	p
	Right		Left			
	Mean ± S.D.	Median (min-max)	Mean ± S.D.	Median (min-max)		
GOLD	440.96 ± 394.51	521 (-125 - 1038)	433.89 ± 408.31	534.5 (-191 - 1053)	386.5	0.928*
BGEL	534.07 ± 443.15	584.5 (-13 - 1421)	518.36 ± 441.83	545.5 (8 - 1547)	369.5	0.712*
PDOH	500.68 ± 350.13	556 (-87 - 1110)	502 ± 350.95	558.5 (-28 - 1215)	-0.014	0.989**
BDOH	556.86 ± 459.6	651.5 (-166 - 1402)	545.86 ± 448.62	654 (-140 - 1408)	381	0.857*

*Mann Whitney U Test; ** Independent Samples t Test; GOLD: Gold standard; BGEL: Ballistic gel; PDOH: Play dough; BDOH: Bread dough

Table 5. Comparison of gold standard and simulation models values according to locations

Soft Tissue Type	Location				Test Statistics	p
	Anterior		Posterior			
	Mean ± S.D.	Median (min-max)	Mean ± S.D.	Median (min-max)		
GOLD	504.17 ± 389.01	553.5 (-111 - 1038)	387.38 ± 403.08	389 (-191 - 1053)	312.5	0.236*
BGEL	677.79 ± 496.6	725.5 (75 - 1547)	412.53 ± 356.48	282.5 (-13 - 935)	246.5	**0.023***
PDOH	599.83 ± 346.39	593 (97 - 1215)	427.47 ± 334.48	352.5 (-87 - 1033)	1.88	0.066**
BDOH	687.63 ± 446.87	715 (133 - 1408)	449.16 ± 431.29	338 (-166 - 1168)	261.5	**0.043***

*Mann Whitney U Test; ** Independent Samples t Test; GOLD: Gold standard; BGEL: Ballistic gel; PDOH: Play dough; BDOH: Bread dough

No significant difference was found between the medians of the anterior and posterior gray values of the gold standard and play dough (p=0.236, p=0.066, respectively). A significant difference was found between the medians of the anterior and posterior gray values of ballistic gel and bread dough (p=0.023, p=0.043, respectively). In the gold standard and all simulation models, the medians of gray values obtained in the anterior were higher than in the posterior.

The comparison of the mean and median data of the gray values obtained according to the selected tissues is shown in Table 6. A significant difference was found between the medians of the gray values obtained from the gold standard and all simulation models ($p < 0.001$). In addition, gray values obtained from teeth and bone statistically differed from those obtained from pulp and soft tissue.

The correlation between the gray values obtained with protocols A and B, which are the CBCT exposure procedures in the study, is shown in Table 7. A very high, positive, significant correlation was found between protocols A and B of all simulation models. The highest positive significant correlation of the gold standard protocol A was found with the ballistic gel simulation protocol B ($r = 0.893$, $p < 0.001$). The highest positive significant correlation of the gold standard protocol B was found with the play-dough simulation protocol A ($r = 0.943$, $p < 0.001$).

Table 6. Comparison of gold standard and simulation model values according to selected tissues

Soft Tissue Type	Selected tissue				Test Statistics	p*
	Tooth	Pulp	Bone	Soft tissue		
GOLD	896.75 ± 152.11	110.58 ± 290.94	703.94 ± 140.22	71.56 ± 93.76	41.824	**<0.001**
	942.5 (532 - 1053)[b]	-32 (-191 - 580)[a]	681 (492 - 938)[b]	57.5 (-111 - 286)[a]		
BGEL	1023.5 ± 319.92	307.25 ± 348.82	746.69 ± 234.16	97 ± 37.89	34.387	**<0.001**
	881 (657 - 1547)[b]	102.5 (-13 - 833)[a]	737 (418 - 1084)[b]	98.5 (8 - 179)[a]		
PDOH	899.42 ± 214.1	210.5 ± 319.89	677.25 ± 166.43	245 ± 91.98	36.375	**<0.001**
	886.5 (630 - 1215)[b]	53 (-87 - 789)[a]	704.5 (354 - 881)[b]	280.5 (97 - 351)[a]		
BDOH	1108.92 ± 242.54	322.17 ± 343.67	769.63 ± 153.36	86.81 ± 132.66	38.805	**<0.001**
	1100 (789 - 1408)[b]	141 (-7 - 868)[a]	772 (491 - 999)[b]	145.5 (-166 - 191)[a]		

*Kruskal Wallis Test; Mean ± S.D.; Median (min – max); a-b: There is no difference between groups with the same letter

Table 7. Correlation of values obtained from protocol A and protocol B exposure procedures

Soft Tissue Type		GOLD -B-	BGEL -B-	PDOH -B-	BDOH -B-
GOLD -A-	r	0.925*	0.893*	0.878*	0.877*
	p	**<0.001**	**<0.001**	**<0.001**	**<0.001**
BGEL -A-	r	0.851*	0.916*	0.883*	0.908*
	p	**<0.001**	**<0.001**	**<0.001**	**<0.001**
PDOH -A-	r	0.943*	0.909*	0.940**	0.879*
	p	**<0.001**	**<0.001**	**<0.001**	**<0.001**
BDOH -A-	r	0.913*	0.933*	0.908*	0.940*
	p	**<0.001**	**<0.001**	**<0.001**	**<0.001**

*Spearman's rho Correlation Coefficient; **Pearson Correlation Coefficient; A: Protocol A (FOV: 8x15cm, 90kVp, 6.3mA, 4.5s, 574 mGy cm2); B: Protocol B (FOV: 13x15cm, 90kVp, 5mA, 8.1s, 823 mGy cm2)

DISCUSSION

Compared with the gold standard gray values with simulation models, a high or very high positive significant correlation was detected in all tissues except soft tissue. The low level of positive correlation detected for soft tissues may be related to the fact that all simulators used can not fully represent the original tissues, such as muscle, tendon, and skin surrounding the sheep's skull. A previous study found no significant difference between ballistic gel and the gold standard for soft tissue values [5]. The reason for the difference with the present study may be the change in x-ray penetration properties caused by the exposure parameters used. While 90kVp and >5mA were preferred in the protocols in the present study, 80 kVp and <4mA were selected in the previous study. In addition, variables such as preferred mixing ratios and room temperature during the preparation of the ballistic gel and anatomical differences between the farm animals (pigs and sheep) selected as samples may also have affected the results.

No statistical difference was found only in the gold standard when the gray values between the mandible and maxilla were compared. In all simulation models, it was observed that the gray value level obtained from the mandible was higher than that of the maxilla, and there was a significant difference between the two jaws. Although numerical data have not been shared, when the graphs presented are examined, it is observed that the gray values obtained in the mandible are higher than in the maxilla in the previous study [5], too. This may be related to the fact that in farm animals, as in humans, the mandible appears more radiopaque because it contains more cortical alveolar bone than the maxilla. Although there is no statistical difference between jaws in the gold standard, the difference between jaws in simulation models may be due to the change in gray values obtained in the mandible. It is observed that the gray values of the mandible obtained with the simulation models are higher than the gold standard. In contrast, the gray value levels obtained from the maxilla in the gold standard and other simulation models are similar. This may be because the soft tissue surrounding the mandible has a compact structure and its thickness is lower than that of the maxilla, thus making it more difficult to simulate the original thickness compared to the maxilla.

Although there is no significant difference between the gray values obtained in the gold standard and play-dough simulation according to anterior and posterior localization, the difference in bread dough and ballistic gel may be related to the viscosity values of the simulation materials that affect the manipulation. Ballistic gel can become more fluid at room temperature, and bread dough has an unstable form [9]. This makes it difficult to position bread dough and ballistic gel on the sheep's head for a long time, especially in the anterior region. The fact that the gray values obtained in the anterior region in ballistic gel and bread dough simulation are higher than in the gold standard and play-dough simulation may be related to the manipulation sufficiency.

It is an expected result that there is a statistical difference between the gray values obtained from the selected tissues, both in the gold standard and in all simulation models. In addition, while pulp and soft tissue gray values are similar, tooth and bone gray values show statistical agreement. Considering these findings, the fact that there is no statistically significant difference between the gray values obtained in both the gold standard and simulation models between the right and left sides suggests that the simulation models were prepared by ensuring homogeneous distribution, and an ideal simulation modeling was performed.

No significant differences were found between CBCT protocols, and a high level of agreement was detected between simulations and protocols. In determining the protocols, the FOVs and kVp values most frequently preferred in the clinic were taken as the basis. The highest correlation obtained was between gold standard protocol B and play-dough protocol A ($p=0.943$). Although the thickness of the play dough is prepared similarly to the original tissue, its different structures and densities may require changes in some parameters in the CBCT imaging procedure to ensure optimum correlation in gray values.

In the gray value analysis performed according to jaws and localization, the correlation of the gold standard and ballistic gel was partially less successful than play dough and bread dough. This finding suggests that play-dough and bread-dough may be a preferable alternative to ballistic gel as soft tissue simulation materials. Ballistic gel was the simulation material that showed the highest correlation with the gold standard in gray values of the tooth and bone. This finding is consistent with the results of the study in which ballistic gel was shown to be a more successful simulation material than wax and ice [5]. In the present study, in addition to teeth, bone, and soft tissue, pulp was also added to the tissues subjected to gray value analysis. Measurement of pulp volume and morphological analysis of the pulp are frequently preferred today, especially in age determination research [17]. Since it is a relatively small anatomical structure, successful simulations are needed in CBCT images obtained in ex vivo dental pulp studies so that precise measurements on the pulp are not questionable in terms of data reliability. The fact that the highest correlation of pulp gray values with the gold standard in the present study was obtained in play-dough simulation shows that play-dough can be an alternative soft tissue simulator in ex vivo studies related to pulp morphology.

The term "Gray value" is preferred to "HU" in the present study because it is a more generally accepted expression. The use of the HU feature added to the CBCT software in studies on gray values raises doubts about the validity of the data obtained. Because it is accepted that CBCT gray values are not the exact equivalent of HU [3]. However, in studies planned to increase the diagnostic accuracy of dental volumetric tomography devices and software, the limitation of alternative options for data analysis leads to the continued use of the HU feature in CBCT. On the other hand, image processing programs such as ImageJ, where images obtained with CBCT are transferred, are also used for gray value analyses [5]. Furthermore, the accuracy and stability of grayscale values derived from CBCT for evaluating bone density appear to be inferior to that of HU derived from CT [3,18]. However, the presentation also showed a strong correlation between the grayscales of the CBCT scan and the HUs of the CT scan [19]. According to a recent publication, CBCT-HU feature can be used to assess bone density using the 'HU' option in Simplant software [20,21]. In both cases, the physical properties of substances under CBCT-induced radiation exposure may not be fully represented. Nonetheless, it can be said that the contribution of studies similar to the present study to the aim of improving CBCT image quality is valuable. Future research may overcome the reliability issue of HU-like values derived from CBCT by using methods such as artificial intelligence or advanced image processing algorithms.

It is a common practice to use a bolus in radiotherapy to protect healthy tissues and to deliver optimal doses [22] effectively. The material to be used as a bolus is expected to provide advantages in terms of visibility, availability, toxicity, and cost, and the HU value in tomography imaging is expected to be between 130 and 160. It has been shown that play-dough is frequently used as a bolus material and gives very successful results with its alternatives. It is stated that the change in the thickness of the bolus positioned on the skin significantly affects the dose effectiveness [12]. The purpose of choosing play-dough is different between the present study and the studies in which it was used as a bolus material. However, the advantages of play-dough, such as its HU value being very close to soft tissue values ranging between 40-80 HU [23], its non-toxic properties, and being easy to manipulate, confirm that it is suitable for use as a soft tissue simulator.

In this study, bread dough was also tested in addition to the play dough, which was chosen as an alternative to ballistic gel. Play-dough is a product prepared by manufacturers with certain ingredients and mixing ratios. By testing bread dough as a soft tissue simulator, it was aimed to show whether it is successful for researchers to prepare without the need for any manufacturer support, easily. Its viscosity can be manipulated by changing the proportions of the ingredients in its structure while preparing bread dough. Although this may seem like an advantage, it may lead to the inability to create a reproducible methodology for future studies, as can the use of a partially standardized material such as play-dough.

Additionally, it was observed that the bread dough simulation had quite a lot of porosity in the CBCT images. Play-dough simulation is observed homogeneously in CBCT images, probably because it was exposed to processes such as pressing or vacuuming during production. The porosity level can be changed by changes in the method while preparing the bread dough simulation material. On the other hand, the porosity in the structure of bread dough may have been effective in giving more successful results than other simulation models in the mandible and anterior region, which have more cortical bone tissue compared to the maxilla and posterior region.

Since it may be difficult to maintain the form of the ballistic gel at room temperature, manipulation time may be negatively affected. For this reason, the use of play-dough may be more advantageous than ballistic gel because the manipulation time of play-dough can take up to 12 hours according to the manufacturer's information [11]. In addition, play-dough is a cheap material that does not require a preparation process like ballistic gel and is easily available. Play-dough, which still allows manipulation even though the color distinction has been distorted and its educational quality has disappeared, can be re-evaluated by obtaining it from preschool education institutions such as "kindergarten".

Limitations

Since the present study was an ex vivo study using a sheep's head, simulation materials could not be tested in human tissue. Although sheep morphology and anatomical landmarks are similar to humans, and there is a similar previous study with another farm animal in the literature, sample choice is one of the limitations of this study. The most important limitation of the study is that maxillary anterior tooth and pulp data could not be obtained due to the anatomical presence of a maxillary incisive region instead of a maxillary incisive tooth in sheep. Additionally, although two observers performed the ROI selection simultaneously and by consensus, minor differences may have occurred between the gold standard and the simulations. Because a single dataset was collected collaboratively, comparisons of intraobserver and interobserver reliability, which would be useful for comparison with similar studies in the literature, cannot be made. Literature was taken as reference in the methodology of the present study, and this foundational research that paves the way for more extensive studies in the field can be considered as a pilot study in which play-dough and bread-dough were tested as soft tissue simulators. Although gray values are not suitable for use in CBCT imaging, their interpretation with the HU software feature in the CBCT device is another important limitation. Finally, although two different exposure protocols were used, the use of a single CBCT device can also be considered among the limitations.

CONCLUSION

Regardless of location, the highest positive significant correlation with the gold standard in gray values was observed in play dough, particularly in the pulp and soft tissue. In the current study, the highest correlation of pulp gray values with the gold standard was obtained in the play dough simulation, suggesting that play dough, with its low cost and ease of manipulation, could be an alternative soft tissue simulator to ballistic gel, particularly in ex vivo studies of pulp morphology.

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