Effects of Three Soft Tissue-Mimicking Materials on Intraoral Radiography Density: A Comparison Using DIGORA for Windows

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Abstract

Recently, different materials in various thicknesses have been suggested for soft tissue replacement. The study intended to compare wax, acrylic, and tissue conditioner used for soft tissue replacement in oral and maxillofacial radiology. In this experimental study, 20 dry human mandibles were used. Each of these bones had at least two posterior teeth. Study materials-acrylic, dental wax, and tissue conditioner—were used to make 10×10 cm blocks with different thicknesses (5, 10, 15, and 20 mm) for soft tissue replacement. All blocks received similar exposure conditions. Data were analyzed in SPSS 22 using ANOVA and t-test. In enamel, the radiographic densities of wax, acrylic, and tissue conditioner with 20 mm thickness, wax and tissue conditioner with 15 mm thickness, and tissue conditioner with 10 mm thickness were significantly different from that of the control group ($P<0.05$). In Cementoenamel Junction (CEJ), all materials with a thickness of 20 mm, acrylic and tissue conditioners with a thickness of 15 mm, and tissue conditioners with 10 mm thickness had radiographic densities significantly different from the control group ($P<0.05$). In the alveolar crest, all materials with a thickness of 20 mm were significantly different from the control group in radiographic density ($P<0.05$). Finally, in dentin at furcation, all the study materials with 20 mm, 15 mm, and 10 mm thicknesses were significantly different from the control group ($P <0.05$). The type of tissue-mimicking material and also its thickness has an impact on the density of digital radiographs taken from dental and bone tissue.

Keywords: *Soft-tissue simulator, Radiographic density, Wax, Acrylic, Tissue conditioner*

Introduction

Phantoms are used in maxillofacial imaging studies for tissue replacement in the patients' heads and cervical areas. Therefore, the materials used for phantom production should have properties that are as similar to those of the human tissues as possible [1] and simulate the interaction between electromagnetic radiation and human tissues [2] for increased validity of the imaging studies and avoidance from excessive and unnecessary exposures of the patients [1]. According to the principles of ALARA, any unnecessary exposure of the individuals for radiographic imaging studies should be avoided [3].

A substance that absorbs or scatters X-rays similarly to human body tissues could be a viable alternative for phantom production. Furthermore, such materials should be precisely measurable, renewable, readily available, and usable in a variety of environmental conditions [2].

However, before a new radiographic receptor can enter clinical trials, in vitro studies should assess its diagnostic validity by using dental radiographic studies. In these studies, the soft tissue replacement by a material located between the x-ray source and the bone or tooth is of great importance because the soft tissue alters the radiation absorption, increases its scattering, and may affect the contrast and density of the radiography film, thereby altering the diagnostic validity of the imaging studies [4].

In recent years, various materials with varying thicknesses have been proposed for soft tissue replacement. Water was the first material used in studies as a soft tissue simulator, and it is still being studied today [5]. However, measuring the thickness of this material is difficult. Furthermore, it is difficult to place the plastic bags containing water in a reproducible position [6-8].

Wax [1, 4, 9, 10] and acrylic [1, 4, 11, 12] are the most commonly studied soft tissue-mimicking materials. Other materials, such as frozen wood and bovine tissue, have been studied as well [1, 13, 14]. However, the material thickness has been randomly selected in most studies, and only a few studies have systemically investigated the ability of these materials in creating a contrast similar to human soft tissue. Therefore, standardization and evolution of phantoms to have a density similar to the facial soft tissue seem necessary.

Previous studies have used different methods to measure the density of the radiographic images, including densitometer, pixel intensity, etc. However, we used DIGORA for Windows for density measurement of the digital radiography. This software, in addition to its accessibility and ease of use, provides us with a novel method of measuring density.

In previous studies, wax and acrylic were frequently used. They are also readily available and simple to use. However, in addition to these materials, the tissue conditioner was used as a soft tissue-mimicking material in this study. Therefore, we planned to compare wax, acrylic, and tissue conditioner in maxillofacial radiographic studies for soft tissue replacement.

Materials and Method

The present study was an experiment with 20 dried human mandibles. Each of these bones had at least two molars. Study materials, including acrylic, dental wax, and tissue conditioner, were used to make 10×10 cm blocks with thicknesses of 5, 10, 15, and 20 mm. A size 2 digital phosphor plate scanner (Kavo, Germany) was placed parallel to the molar/premolar region and was fixed inside a pre-prepared mold (as shown in Figure 1). Then, the blocks made of tissue-mimicking material were placed between the X-ray source (Minray soredex, Helsinki, Finland) and the dried mandible. All the blocks underwent exposure under the same conditions and exposure settings (peak voltage: 60 kvp, electric current: 7 mA, duration: 0.4 s, distance between film and x-ray tube: 30 cm). Moreover, the beam projection orientation was perpendicular to the scanner. Additionally, an episode of exposure was performed without the soft tissue-mimicking material.

The phosphor plate was processed by a PCT device (Soredex-Helsinki, Finland), and the image density was measured and recorded at 4 points in dental and bony regions (as shown in Figure 2) by 2 independent observers using the DFW software version 2.7. The observers recorded their comments separately. Finally, the comments of the observers were collected and analyzed. Each point was imaged three times to improve measurement accuracy.

The data was analyzed using SPSS 22 and the statistical test of ANOVA and t-test. The significance level was considered at $P<0.05$.

This study was approved by the Ethics Committee of the Babol University of Medical Sciences with the approval code of IR.MUBABOL.REC.1399.142.

Results

The one-way ANOVA and Dunnett's post hoc test were used to compare the radiographic density between the blocks with different material types and thicknesses in each point and also investigate the differences with the control group (without tissue-mimicking material). The following results were obtained:

At point 1 (enamel border), the radiographic densities of 20-mm thick blocks made of all the study materials, including wax, acrylic, and tissue conditioner, were significantly different from that of the control group (table1). Moreover, the radiographic densities of 15-mm thick blocks made of wax and tissue conditioner, as well as the 10-mm thick blocks made of tissue conditioner, were significantly different from that of the control group ($P<0.05$).

At point 2 (cementoenamel junction), the radiographic densities of 20-mm thick blocks made of all the study materials, including wax, acrylic, and tissue conditioner, were significantly different from that of the control group (table2). Moreover, the radiographic densities of 15-mm thick blocks made of acrylic and tissue conditioner, as well as the 10-mm thick blocks made of tissue conditioner, were significantly different from that of the control group ($P<0.05$).

At point 3 (alveolar crest), the radiographic densities of 20-mm thick blocks made of all the study materials, including wax, acrylic, and tissue conditioner, were significantly different from that of the control group(table3) ($P<0.05$).

At point 4 (dentin at furcation), the radiographic densities of blocks with 20 mm, 15 mm, and 10 mm thicknesses made of all the study materials, including wax, acrylic, and tissue conditioner, were significantly different from that of the control group (table4)(P <0.05).

Discussion

The present study used 3 materials of wax, acrylic, and tissue conditioner in four thicknesses of 5, 10, 15, and 20 mm for mandibular soft tissue replacement. All thicknesses, except for 5 mm, were found to have a significant difference in radiographic density when compared to the control group.

In the study, we used a control group (without tissue-mimicking material) to compare the radiographic density of the study materials with the control group. Therefore, the control group was the basis to determine the significance of changes in radiographic density.

According to a study by Souza et al., digital radiographic images obtained using different tissue-mimicking materials with the same thickness had different densities in the mandibular region [13], which was compatible with our results. Moreover, Molon et al. showed that the material type and thickness did not affect the radiographic density of dental tissue [14]. This finding was not compatible with our findings because, in our study, density changes were investigated in both dental and bony regions (alveolar crest), and the changes were significant in both regions. However, the study by Molon et al. reported only the changes in the bony regions. This difference in results can be explained by different scanners and density measurement methods used. We used a digital photostimulable phosphor (PSP) plate scanner for imaging and the DIGORA for Windows for image analysis, while Molon et al. used a charge-coupled device sensor for imaging and the methods of Pixel Intensity (PI) and Digital Subtraction Radiography (DSR) for density measurement.

Gegler et al. used a 20-mm thick acrylic block as a maxillary tissue-mimicking material for facial soft tissue simulation. However, none of the study thicknesses showed a significant difference with the patient as the control. Therefore, acrylic blocks with thicknesses of 4, 8, 12, 15, 20, 24, 28, 32, 36, 40, and 45 mm all could be used for facial soft tissue replacement [15]. However, our study showed that acrylic with thicknesses of 10, 15, and 20 mm could change the image density.

Despite the hypothesis that conventional radiography films can show the significant differences between the presence and lack of soft tissue-mimicking materials, it is worth mentioning that the application of digital radiography has been growing in recent years. Therefore, it is necessary to investigate the differences between digital and conventional radiography systems. However, we recommend comparing the present study results with further studies in the future to illustrate the most suitable material type and thickness for soft tissue replacement.

In the present study, we selected the materials based on their availability and reproducibility. Material thicknesses were selected considering the previous studies on real patients. Therefore, 4 thicknesses of 5, 10, 15, and 20 mm were used for each material.

The lack of a gold standard for comparing the density of soft tissue-mimicking materials was one of the study's limitations. Some studies used piglets' heads as a gold standard because the maxillary and mandibular structures of piglets are anatomically similar to human heads. The fresh piglet heads with excellent preservation (no hard or soft tissue damage) were used as the gold standard in some studies [16]. Some other studies used human cases as the gold standard. For example, Maria et al. used the radiographies of the left mandibular molars of 20 patients [1]. However, it seems that these cases can be considered as a human group rather than a gold standard because the sample sizes used to introduce these items as the gold standard were small and limited.

One of the study's strengths was that each imaging was performed three times and the mean value was used. This could increase the measurement accuracy. Furthermore, we used a novel tissue conditioner material that had not been used in previous studies.

Conclusion

The present study showed that the type of soft tissue-mimicking material (wax, acrylic, and tissue conditioner) and its thickness were both effective on the density of radiographic images obtained from dental and bony tissues.

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Conflict of interest

None.

Financial Support

None.

Ethics Statement

All Permissions to conducting this research has been approved.

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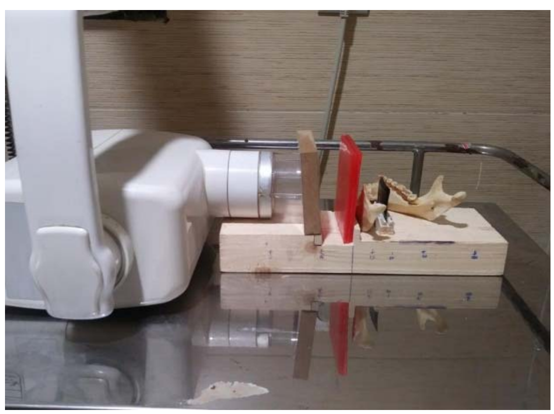

Figure 1: dry mandible and phosphor plate in a pre-prepared mold

Figure 2:

1. Enamel border

2. The cementoenamel junction
3. The junction between the crown and alveolar bone (alveolar crest)
4. Dentin border at furcation

Table 1: Comparisons between the mean values of radiographic density of blocks made of different materials with different thicknesses at Point 1 (enamel border).

Material / **Thickness**	**Wax**	**Acrylic**	**Tissue conditioner**
	Mean ± Standard deviation (difference with control)		
Control (without tissue-mimicking material)	87.76±15.45 (0)[a]	87.76±15.45 (0)[a]	87.76±15.45 (0)[a]
5 mm	87.86±15.96 (0.10)[a]	88.31±11.38 (0.55)[a]	92.35±10.08 (4.58)[a]
10 mm	95.73±7.07 (7.96)[a]	90.51±12.55 (2.75)[a]	101.46±13.49 (13.70)[b]
15 mm	98.26±8.81 (10.50)[b]	93.00±13.82 (5.23)[a]	103.41±15.09 (15.65)[b]
20 mm	103.21±13.55 (15.45)[b]	102.58±11.67 (14.81)[b]	110.20±14.11 (22.44)[b]
Significance level*	P<0.001	P<0.003	P<0.001

*one-way ANOVA

In each column, letters different from the control group (a) indicate a difference at the significance level of 0.05 calculated using Dunnett's post hoc test.

Table 2: Comparisons between the mean values of radiographic density of blocks made of different materials with different thicknesses at Point 2 (cementoenamel junction).

Material / Thickness	Wax	Acrylic	Tissue conditioner
	Mean ± Standard deviation (difference with control)		
Control (without tissue-mimicking material)	38.13±11.09 (0)[a]	38.13±11.09 (0)[a]	38.13±11.09 (0)[a]
5 mm	39.58±10.88 (1.54)[a]	43.16±9.63 (5.03)[a]	43.25±18.64 (5.11)[a]
10 mm	42.76±9.48 (4.63)[a]	45.93±12.40 (7.80)[a]	48.71±12.62 (10.58)[b]
15 mm	46.25±9.56 (8.11)[a]	49.08±8.43 (10.95)[b]	50.05±12.40 (11.91)[b]
20 mm	54.71±11.24 (16.58)[b]	52.60±14.66 (14.46)[b]	59.10±10.96 (20.96)[b]
Significance level*	P<0.001	P<0.002	P<0.001

*one-way ANOVA

In each column, letters different from the control group (a) indicate a difference at the significance level of 0.05 calculated using Dunnett's post hoc test.

Table 3: Comparisons between the mean values of radiographic density of blocks made of different materials with different thicknesses at Point 3 (alveolar crest).

Material / Thickness	Wax	Acrylic	Tissue conditioner
	Mean ± Standard deviation (difference with control)		
Control (without tissue-mimicking material)	17.46±5.76 (0)[a]	17.46±5.76 (0)[a]	17.46±5.76 (0)[a]
5 mm	17.83±5.71 (0.41)[a]	18.05±8.20 (0.58)[a]	17.56±4.02 (0.90)[a]
10 mm	18.20±5.30 (0.73)[a]	20.48±7.07 (3.01)[a]	18.53±5.34 (1.06)[a]
15 mm	21.85±8.41 (4.38)[b]	21.08±3.63 (3.61)[a]	19.01±5.87 (1.55)[a]
20 mm	23.93±7.33 (6.46)[b]	23.81±6.87 (6.35)[b]	24.46±6.48 (7.00)[b]
Significance level*	P<0.007	P<0.002	P<0.001

*one-way ANOVA

In each column, letters different from the control group (a) indicate a difference at the significance level of 0.05 calculated using Dunnett's post hoc test.

Table 4: Comparisons between the mean values of radiographic density of blocks made of different materials with different thicknesses at Point 4 (dentin at furcation).

Material / Thickness	Wax	Acrylic	Tissue conditioner
	Mean ± Standard deviation (difference with control)		
Control (without tissue-mimicking material)	38.36±9.56 (0)[a]	38.36±9.56 (0)[a]	38.36±9.56 (0)[a]
5 mm	41.73±10.40 (3.36)[a]	43.63±10.37 (5.26)[a]	42.53±10.33 (4.16)[a]
10 mm	46.75±11.60 (8.38)[b]	51.45±11.63 (13.08)[b]	48.15±11.89 (9.78)[b]
15 mm	48.58±9.05(10.21)[b]	52.55±10.07 (14.18)[b]	50.38±10.77 (12.01)[b]
20 mm	57.55±8.01 (19.18)[b]	60.61±12.93 (22.25)[b]	57.25±13.62 (18.83)[b]
Significance level*	P<0.001	P<0.001	P<0.001

*one-way ANOVA

In each column, letters different from the control group (a) indicate a difference at the significance level of 0.05 calculated using Dunnett's post hoc test.