RESEARCH

Validity of wax and acrylic as soft-tissue simulation materials used in *in vitro* radiographic studies

L Schropp^{*,1}, NS Alyass², A Wenzel³ and A Stavropoulos⁴

¹Prosthetic Dentistry, Department of Dentistry, Aarhus University, Aarhus, Denmark; ²Department of Dentistry, Aarhus University, Aarhus, Denmark; ³Oral Radiology, Department of Dentistry, Aarhus University, Aarhus, Denmark; ⁴Periodontology, Department of Dentistry, Aarhus University, Aarhus, Denmark

Objective: To determine the thickness of wax and acrylic that provides a radiographic density similar to that of the human cheek.

Methods: An intraoral film radiograph of the human cheek including a 40 × 30 × 3 mm reference aluminium block was recorded under standardized conditions in 61 subjects. Radiographic density was measured by a densitometer in ten randomly selected sites of the film to serve as the gold standard for density values of the cheek soft tissues. Thereafter, the density of series of radiographs of two tissue-simulating materials—wax and acrylic—in systematically increasing thicknesses (wax, 1.5–30 mm; acrylic, 2–40 mm) plus the reference block were measured and compared with the gold-standard values.

Results: The radiographic density of wax with a thickness of 13–17 mm or acrylic with a thickness of 14.5 mm corresponded to the average density of the human cheek.

Conclusion: The soft tissues of the average human cheek can be simulated with 13–17 mm wax or 14.5 mm acrylic in *in vitro* radiographic studies.

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Introduction

Before new radiographic receptors enter the clinic, their diagnostic accuracy—for example, in caries lesion detection—is usually tested in *in vitro* dental radiographic studies using human specimens (*e.g.* extracted teeth alone or in dry mandibles). In most of such studies it has been considered important to simulate the soft tissues (cheek) by using a material interposed between the X-ray beam and the teeth/bone, because soft tissues change the absorption and increase scatter radiation, and may influence the contrast and density of the film (and thereby diagnostic accuracy). In fact, Souza et al¹ showed that animal fat samples of different thicknesses used as a soft-tissue simulator adjacent to the mandibular retromolar region influenced the resulting grey level values in digitized intraoral radiographs.

In recent years, materials in various thicknesses simulating soft tissues have been proposed to mimic

the clinical situation. Dental wax 10–20 mm thick^{2–5} and various acrylics 5–25 mm thick^{6–20} are among the most frequently used materials. However, in most of the studies both the type of material and the thickness have been chosen haphazardly, and only a few studies have systematically evaluated the appropriateness of these materials in terms of providing changes in density on a par with human soft tissues.^{21,22} In context, standardization and development of a phantom with a density similar to that of the cheek soft tissues seems relevant.

The purpose of this study was therefore to determine the appropriate thickness of wax and acrylic that provides a radiographic density similar to that of the human cheek.

Materials and methods

Clinical part

In order to obtain an estimate of the radiographic density representative of the human cheek, 61 subjects

*Correspondence to: Dr Lars Schropp, Prosthetic Dentistry, Department of Dentistry, Aarhus University, Vennelyst Boulevard 9, 8000 Aarhus C, Denmark. E-mail: lars.schropp@odontologi.au.dk
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(19 males and 42 females) with different ethnicities and ages (range 21–62 years) were enrolled in this study. The subjects were divided visually into three subgroups with regard to body size, as an attempt to assure that the group represented the general population: “below normal” ($n=11$), “normal” ($n=42$) and “above normal” ($n=8$). The subjects were recruited among employees and students from School of Dentistry, Aarhus, Denmark, and gave informed consent after verbal information about the project prior to inclusion. There were no exclusion criteria except for pregnancy. The local ethical committee, the Central Denmark Region, gave consent to the study.

An intraoral radiograph was taken of the subjects’ left cheek with a 31×41 mm conventional film (F-speed film, Kodak Insight; Kodak, Rochester, NY). The film mounted in a film holder (Trollbitten; Trollhätteplast, Trollhättan, Sweden) was placed in contact with the posterior cheek mucosa so that part of the masseter muscle was included in the image. This position of the film was chosen to represent a posterior bitewing projection. The film holder was then attached to the tube of the X-ray unit using a muff so that the focus–film distance and angle between the tube and film were similar at all exposures. To facilitate density measurement, a $40 \times 30 \times 3$ mm reference block (CDDent; Artinis Medical Systems B.V., Zetten, Netherlands) consisting of an aluminium base and a cover of poly(methyl methacrylate) (CDDent; Artinis Medical Systems B.V., Zetten, Netherlands) was placed just in front of the film (Figure 1a), and both were covered in a thin rubber glove to avoid sterilization after each exposure. The subject kept the film holder in place with a light manual pressure. The same operator (NSA) recorded all radiographs after careful instruction from an experienced dentist during the first six exposures. All recordings were made with the same X-ray unit (ORALIX AC; Gendex®, Hatfield, PA) and standardized settings (65 kV, 15 mA and 0.32 s). These settings resulted in images with a good contrast and density, as determined by a series of similarly obtained radiographs with different exposure times from a pilot evaluation performed before commencing the current study. All films were processed in fresh X-ray film developer in a fully automatic developer machine (XR24 Nova; Dürr Dental AG, Bietigheim-Bissingen, Germany).

A densitometer (Sakura; Konica, Tokyo, Japan) with a spotlight of 2 mm in diameter and a scale of 0.00–4.00 was used to measure the density of the films. The density was measured at ten randomly, but systematically, chosen spots on the images (*i.e.* spots representing approximately the same position in the peripheral and central aspects of the reference block). The ten measurements were averaged for each film. An average of all measurements was calculated and defined as the average relative density representative of the cheek of the participant, and in addition averages for the three body size groups were calculated.

Laboratory part

Two simulation materials (wax and acrylic) were evaluated. For wax, modelling (base plate) wax sheets (Tenacatin; Kemdent, Swindon, UK) with dimensions of $189 \times 89 \times 1.5$ mm were used. The sheets were cut into $40 \times 30 \times 1.5$ mm pieces and placed sequentially one behind another in increasing number, gently pressed together to avoid any empty space between them but without deforming the wax. For acrylic, microscope slides (Artikel-Nr: 41500; Exakt apparatebau GmbH, Norderstedt, Germany) with dimensions $75 \times 25 \times 2$ mm were used and placed sequentially one behind another in increasing number, gently pressed together to avoid any empty space between them.

In order to get an idea of the relevant thickness range of the materials that would result in similar film densities as those found in the clinical part of the study, 20 sheets/slides of each material (*i.e.* wax = 30 mm and acrylic = 40 mm) were arbitrarily chosen initially. Compared with the density measurements from the clinical part, it was found that these material thicknesses resulted in densities that were too high. Thus, series of radiographs for 20 thicknesses of wax (from 1.5 mm to 30 mm) and 20 thicknesses of acrylic (from 2 mm to 40 mm) were recorded thereafter. The radiographs were taken with the simulating material (wax or acrylic) in increasing thicknesses placed in the film holder in front of the reference aluminium block (Figure 1b,c) and attached to the holder with an elastic band (not interfering with the radiation beam) and with the same exposure parameters as those used in the clinical part. The distance between the simulation material and the reference block corresponded to the distance between the cheek of the subjects

Figure 1 Film holder with film and (a) reference aluminium block alone, and (b) with a wax sheet or (c) an acrylic microscope slide attached to the X-ray tube

and the reference block. In addition, control images were recorded of the reference block wrapped in a rubber glove as well as without a glove to determine a possible effect of the glove on density. All films from the laboratory part were processed in the same type of fresh chemicals and by the same automatic developer machine as those from the clinical part. The density was measured with the same densitometer as used in the clinical part at ten randomly but systematically chosen spots on the images (*i.e.* spots representing approximately the same position in the peripheral and central aspects of the reference block). The ten density measurements were averaged for each film.

Descriptive statistics were used to analyse the data.

Results

The average densities of the cheek exposures according to body size are presented in Table 1. The cheek densities of films from subjects with “normal” and “below normal” body size were very similar (1.76 and 1.77, respectively), while films from subjects with an “above normal” body size had a somewhat lower density (1.65). Figure 2 shows the density measurements of the exposures from wax and acrylic in the various thicknesses (represented by the solid line). The dotted horizontal lines represent the mean density for the subjects of “normal”, “below normal” and “above

Table 1 Average density for the subjects categorized by body size (“below normal”, “normal” and “above normal”)

Body size	Number of subjects	Density
Below normal	11	1.77
Normal	42	1.76
Above normal	8	1.65
Total	61	1.74

normal” body size, and the mean density for the average person in the total group. The range of mean densities for the subjects with “below normal” (1.77), “normal” (1.76) and “above normal” (1.65) body size corresponded to the density of wax with a thickness of 12.5–18.5 mm or of acrylic with a thickness of 12.5–19 mm, while the density for the average person altogether (1.74) corresponded to the density of wax with a thickness of 13–17 mm or of acrylic with a thickness of 14.5 mm.

Control radiographs recorded of the reference block with or without a thin rubber glove showed that the glove had no influence on density.

Discussion

The present study showed that wax and acrylic with thicknesses of 13–17 mm and 14.5 mm, respectively, can simulate the human cheek in *in vitro* radiographic studies. These values are more or less similar to

Figure 2 Density measurements for (a) wax and (b) acrylic in different thicknesses. The left graphs show the full range of thicknesses evaluated; the right graphs show a segment of the left ones. The numbers in the right graph represent the thicknesses of the simulation material, which correspond to the mean densities (represented by the dotted lines) for subjects of “normal” (1.76), “below normal” (1.77) and “above normal” (1.65) body size, as well as for the average person (1.74)

arbitrarily chosen material thicknesses used in previously published radiographic studies. For example, Shi and Li¹⁹ used a 15 mm thick soft-tissue equivalent plastic compound in a study comparing detection of approximal caries *in vitro* by black-and-white and colour-coded digital radiographs, while Castro *et al*⁶ used a 17 mm thick layer of acrylic as a soft-tissue simulation material in a study comparing conventional film and direct digital imaging in the detection of approximal caries lesions. In a recent study by Ulusu *et al*,⁴ 14 mm dental wax was employed to simulate the soft tissues when comparing digital and conventional bitewing radiographs for the detection of approximal caries lesions in primary teeth. Water has also been frequently used as simulation material;^{23,24} however, the quantity may be difficult to standardize, and placement of plastic bags containing water in a reproducible fashion may be cumbersome. Some have used poly(methyl methacrylate) cylinders/boxes filled with water.^{25–27} In the present study, only dental wax sheets and acrylic microscope slides were evaluated because they are cheap, easy to handle and readily available in all dental schools.

In one of the few studies systematically addressing the issue of soft-tissue simulation, 10 mm utility wax was found suitable to substitute muscular tissue.²¹ In another study, Caldas *et al*²² evaluated four different materials (self-polymerizing acrylic resin, utility wax, wood and a 2 mm thick poly(methyl methacrylate) box filled with a 2 mm thick layer of water) in 11 thicknesses (4–45 mm). The results showed that, except for utility wax at a thickness of 4 mm and 8 mm and water at a thickness of 4 mm, all other material thicknesses could be used to simulate soft tissues in intraoral radiography studies.

In the present study, the subjects were divided visually into “below normal”, “normal” and “above normal” body size groups to assure that the sample may represent the average general population (*i.e.* not only over- or underweight persons were included), since it was expected that body size influenced film density. This can be owing to differences in cheek thickness and the relative volumes of the various tissues (*e.g.* muscular *vs* adipose tissue). This seems to be relevant particularly for subjects with “above normal” body size; in the present evaluation, density of subjects with “below normal” body size did not differ much from those with a “normal” body size. Statistical evaluation for significance of those differences was not performed because (i) it was deemed meaningless owing to the

relatively limited number of individuals in each group, and (ii) density variation among different body size individuals seems somehow irrelevant for designing *in vitro* radiographic studies (*i.e.* an *in vitro* study reproducing the situation only in over- or underweight individuals seems improbable).

In a recent study on soft-tissue simulation materials, a digital intraoral receptor has been used instead of a conventional X-ray film.²² However, density (pixel intensity) in images from digital receptors may be automatically adjusted (*i.e.* with no influence from the user) by the software before display.²⁸ Digital receptors therefore have a much wider dynamic range than the conventional film,²⁹ and small differences in matter absorption and scatter will not be discernible in grey shades of pixel distribution. This inherent feature of digital systems can probably explain the large range in thickness suggested for utility wax (12–45 mm) and acrylic (4–45 mm) reported previously.²² By contrast, a narrow range (4 mm) of wax thickness and a single thickness value for acrylic could simulate the average cheek density in our study using conventional film.

In the present study, a reference aluminium block was placed between the film and soft tissue (the cheek) or the simulation materials. The reason for using the reference block was to operate within the useful range of film density (*i.e.* a range in which small differences in exposure due to interindividual variation in cheek thickness or varying simulation material thicknesses will produce relatively large differences in film density), according to the characteristic curve (Hurter–Driffield curve) of a radiographic film.³⁰ If a reference block was not used, the X-ray energy would simply result in saturated (overexposed) radiographs. One may argue that low energy (kV) or short time exposure parameters (mAs) could have been used, or that the cone of the unit could have been moved further away from the patient (increased focus–film distance). However, it seems reasonable to operate with values for voltage similar to those applied in the clinic (60–70 kV), and additionally it must be taken into consideration that dental units do not produce a homogeneous X-ray beam when working with very short exposure times. Moreover, moving the unit further away would result in an inappropriately increased exposure field on the patient's face.

In conclusion, the present study showed that the cheek soft tissues of a person of average size may be simulated using wax with a thickness of 13–17 mm or acrylic with a thickness of 14.5 mm.

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