Radiolucency of cast titanium for detection of internal porosity

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Purpose: The aim of this study was to examine the radiolucency of cast titanium discs having different thicknesses using radiographs taken by a dental X-ray unit under various conditions to detect internal porosity of the cast titanium metal frameworks.
Materials and Methods: Radiographs of eight cast discs (0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, and 5.0 mm thick; 8 mm diameter) were taken on dental occlusal film using a dental X-ray unit under the following conditions: tube voltage: 70 kV or 90 kV, exposure time: 0.25, 0.5, 0.75, 1.0, 1.5, 2.0, 3.0, or 4.0 s. The density levels (0, black-255, white) of the radiographs were measured using computer graphics.
Results: The mean density levels of the radiographs taken at 90 kV dramatically decreased to zero (black, X-ray 100% penetrated) with shorter exposure time and greater disc thickness. When a tube voltage of 70 kV was applied, there was a wide range of exposure times to reach a "0" density level for each disc thickness.
Conclusion: The use of lower voltage and a longer exposure time for dental X-ray unit is appropriate to clearly detect the internal porosity. **(Int Chin J Dent 2004; 4: 72-77.)**

Clinical Significance: Cast titanium frameworks must be examined radiographically before further steps to fabricate the prostheses in laboratory. On the basis of the results obtained in this study, the use of lower voltage and a longer exposure time for dental X-ray unit is appropriate to clearly inspect the internal porosity in cast titanium metal frameworks.
Key Words: cast defect, cast titanium, internal porosity, radiolucency.

Introduction

Cast titanium restorations have been increasingly applied for patient treatment, especially for patients who are allergic to dental alloys,[1] since titanium offers excellent corrosion resistance and biocompatibility. Titanium and its alloys are relatively difficult to cast because of their high reactivity with gasses at high temperatures and their light weight (4.5 g/cm^3) as compared with other dental casting alloys (Co-Cr, 8-9 g/cm^3; Au alloys, 13-16 g/cm^3). Gasses are easily incorporated into molten titanium during casting, resulting in undesirable internal porosity in the cast metal framework, which leads to a high risk of clinical failure. Metal frameworks must be examined carefully for internal porosity to obtain problem-free castings. Radiography is one of the non-destructive methods to check the internal porosity in dental castings,[2-9] especially, in cast titanium due to its low density. Radiographs on industrial or dental films were frequently employed to detect internal porosity of the titanium framworks.[10-19] Wang et al.[10] introduced a simple method of detecting porosity in titanium using a dental X-ray unit and occlusal film. They set the X-ray unit at a tube (peak) voltage of 90 kV, tube current of 25 mA, and 30-s exposure time to take radiographs of a titanium partial denture framework with a 1.2 mm-thick major connector.

Metal frameworks possess different thicknesses, varying from 0.3-0.5 mm for palatal plates to 1.2-2.0

mm for lingual bars, major connectors, and minor connectors. In an extreme case, the pontic and its connectors in a multi-unit fixed partial denture may be 2.0-5.0 mm thick. Therefore, it is necessary to investigate the radiolucency of cast titanium metal frameworks with a large range of metal thickness. In the present study, the radiolucency of different thicknesses of cast titanium was evaluated using radiographs (dental occlusal film) taken by a dental X-ray unit with 70 kV or 90 kV tube voltage and various exposure time to detect internal porosity.

Materials and Methods

Eight acrylic discs of various thicknesses (0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, and 5.0 mm thick; 8 mm diameter) attached to sprue bars were connected on the sprue cone former and invested in a mold ring using a MgO-based investment (Selevest CB, Selec Co., Osaka, Japan). After the investment had set, the mold was burnt-out in a furnace (Accu-Therm III 6000, Jelenko, Armonk, NY, USA) according to the manufacturer's instruction, and was cast with commercially pure titanium (ASTM Grade 2, Titanium Ind., Grand Prairie, TX, USA) using a centrifugal casting machine (Ticast Super R, Selec Co.). The casting procedure followed manufacturer's instructions. After casting, the mold was bench-cooled to room temperature. The cast titanium discs were retrieved, and the surfaces of the cast discs were air-abraded with 50 µm Al_2O_3 particles.

Radiographs of the eight cast titanium discs were taken on dental occlusal film (57x76 mm, Ultra-speed, Kodak, Rochester, NY, USA) using a dental X-ray unit (GX-900, Gendex, Des Plaines, IL, USA) under the following conditions: tube voltage, 70 kV or 90 kV; exposure time, 0.25, 0.5, 0.75, 1.0, 1.5, 2.0, 3.0, or 4.0 s. The tube current and target-film distance were set at constants of 15 mA and 50 cm. Three radiographs of the cast discs were taken for each tube voltage and exposure time. The occlusal films were developed in a dental X-ray film processor (A/T2000 XR, Air Techniques, Hicksville, NY, USA).

The developed radiographs were scanned into a computer using a scanner (hp scanjet 5470c, Hewlett-Packard, Palo Alto, CA, USA) at a resolution of 1,200 dpi, and the density level of radiographs for each disc was measured using computer graphics (Adobe Photoshop 6.0, Adobe Systems Incorporated, San Jose, CA, USA) (density level; 0, black-255, white). The density levels of five areas (each square; 0.5x0.5 mm) for each disc were averaged. The density levels of three radiographs were averaged, totalling 15 measurements for each disc. The areas where small internal porosity was found in the disc were not selected for density level measurements. The data were statistically analyzed using three-way ANOVA with the factors of tube voltage, exposure time, and disc thickness at a significance level of α=0.05.

Results

Fig. 1 shows the radiographs taken by the dental X-ray unit set at 70 kV and 90 kV. The density levels of the occlusal film taken at 70 kV and 90 kV are presented in Figs. 2 and 3, respectively. Compared to the values at 70 kV, the mean density levels of the radiographs taken at 90 kV dramatically decreased to zero (black; 100% X-ray penetrated) with shorter exposure time and greater disc thickness. For example, when a tube voltage of 90 kV was applied, the exposure time to reach a density level of "0" was 1.5 s for 3.0 mm thickness and 2.0 s for 4.0 mm thickness. When a tube voltage of 70 kV was applied, depending of metal thickness the exposure time needed to reach a density level 0 has a wide range and varied between 0.75 s and more than 4 s. The results of the statistical analysis are presented in Table 1. Although statistical significances ($p<0.05$) were found for each factor (tube voltage, exposure time, and disc thickness) and three-way interaction, there were no significances for two-way interactions between tube voltage and exposure time or disc thickness.

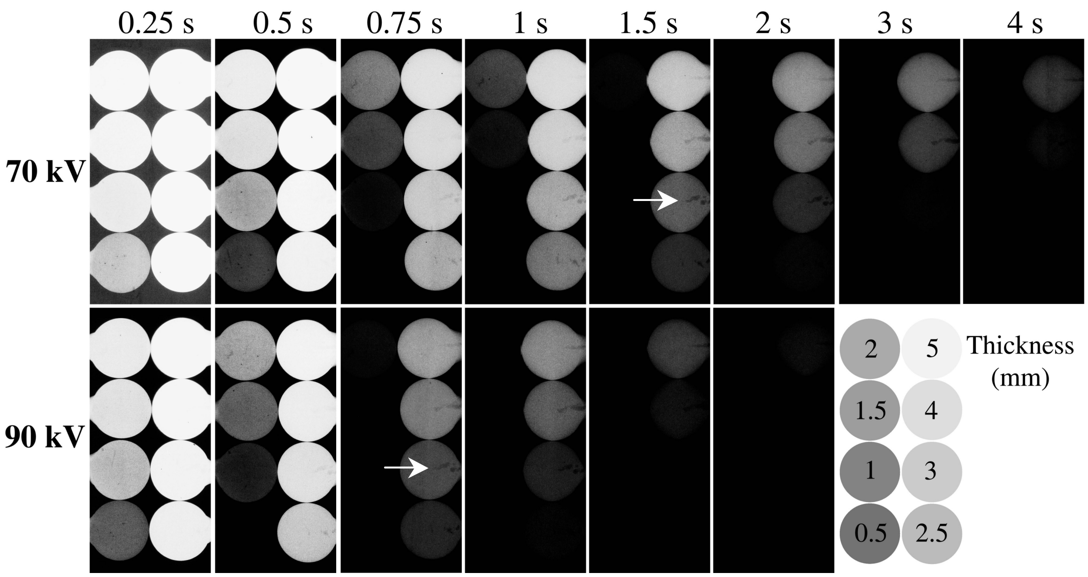

Fig. 1. Radiographs of cast titanium discs with various thickness using a dental X-ray unit. Arrows indicate internal pores of the 3 mm thick disc taken at different conditions (70 kV-1.5 s vs. 90 kV-0.75 s).

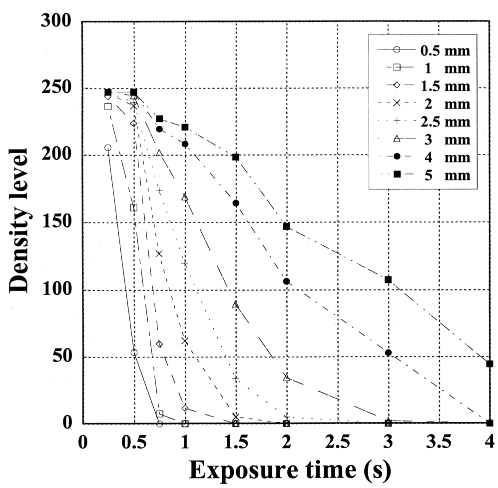

Fig. 2. Film density level taken at 70 kV.

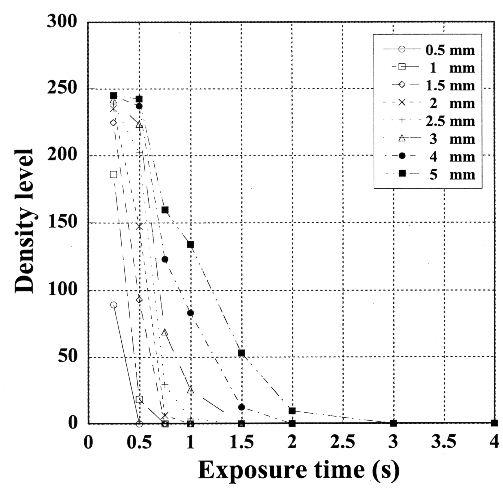

Fig. 3. Film density level taken at 90 kV.

Discussion

When the X-ray beam passes through the different thicknesses of cast titanium discs, its intensity is

Table 1. The results of the three-way ANOVA.

	Sum of square	df	Mean square	F value	p value	Sig.
Tube voltage (a)	306,153.758	1	306,153.758	20.482	0.003	S
Exposure time (b)	3,801,149.904	7	543,021.415	29.982	0.000	S
Disc thickness (c)	957,181.298	7	136,740.185	10.203	0.000	S
a x b	89,942.883	7	12,848.983	2.127	0.058	NS
a x c	56,972.044	7	8,138.863	1.347	0.249	NS
b x c	553,823.284	49	11,302.516	1.871	0.015	NS
a x b x c	295,961.381	49	6,040.028	346.612	0.000	S
Error	8,922.068	512	17.426			

S, significant; NS, not significant at α=0.05.

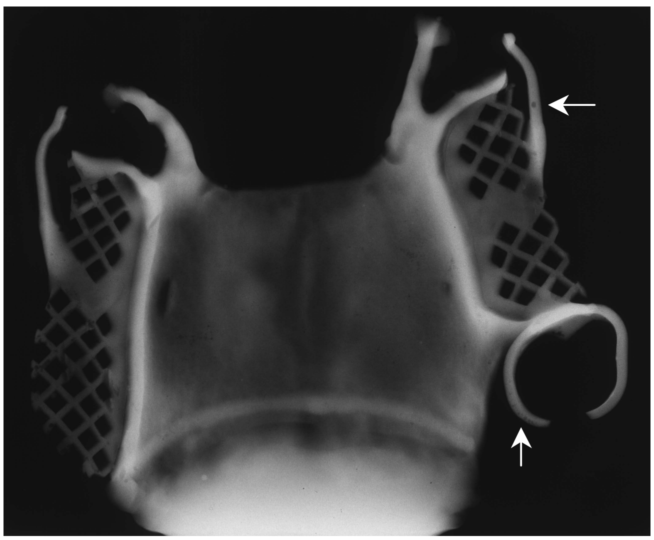

Fig. 4.
Radiograph of a cast titanium partial denture framework taken at 70 kV-1.5 s.
Arrows indicate internal pores of the left-side I-bur and the left molar lingual clasp.

reduced by absorption or scatter in the cast titanium. As a result, the different beam intensities change the optical density of the radiographs. When one considers the number of photons in an X-ray beam, *n*, as it passes through a thin layer of attenuating material, a relatively small number, Δn, are absorbed or scattered in the layer (thickness of the layer; Δx)[20]

$$\Delta n = -\mu \cdot n \cdot \Delta x$$

where, μ is the linear attenuation coefficient. The minus sign is used because *n* refers to the photons remaining in the beam that are unaffected by matter. $\mu \cdot n \cdot \Delta x$ photons are removed from the beam by the layer, so the change Δn in the total number still in it is negative. The linear attenuation coefficient is a function of the density, ρ, the atomic number of the irradiated medium, Z, and the energy of the photons that constitute the x-ray beam, $h\nu$ (h; Planck's constant, 6.626×10^{-34} J·s: ν; frequency of the radiation):

$$\mu = \mu\,(\rho, Z, h\nu)$$

The same argument applies to the X-ray beam's energy fluence and to its intensity, *I*.

$$\Delta I = -\mu \cdot I \cdot \Delta x$$

Compared to other elements included in dental casting alloys, titanium has relatively low density, ρ (4.5 g/cm^3) and atomic number, Z (22), resulting in a relatively higher radiolucency (low ΔI) as observed on the occlusal film employed for dental use.[9,10]

When low tube voltage (70 kV) was used to inspect the cast titanium discs for internal porosity, the radiographs had wide ranges of film density level and exposure time for various metal thicknesses. The use of low-energy X-rays enhances the photoelectric contrast.[20] If lower-energy X-rays are used, subtle differences in the amounts of photoelectric attenuation occurring in different substances (because of differences in their densities and atomic numbers) may be enhanced, and may result in greater contrast in a radiograph. Therefore, internal porosity in cast titanium may be more clearly detected by applying lower tube voltages and longer exposure times. This finding can be confirmed by examining the two radiographs that show similar density levels for titanium discs with the same thickness (3.0 mm) under two different conditions: 70 kV-1.5 s vs. 90 kV-0.75 s (as shown by arrows in Fig. 1). The internal pores in the radiograph taken at 70 kV-1.5 s are more apparent compared with those found in radiographs taken at 90 kV-0.75 s.

When one considers the optimal conditions (tube voltage and exposure time) for taking radiographs to detect the internal porosity in metal frameworks of different thicknesses, it is necessary either to choose a condition covering a certain range of film density levels for different metal thicknesses, or to take several radiographs under different conditions. Based on the radiographs and the data obtained in this study, density levels between 50 and 200 seem to be appropriate for detecting internal porosity. Compared to the values at 90 kV, there was a wide range of exposure times at 70 kV that produced a density level between 50-200 for different metal thicknesses. Therefore, within the limits of this study, radiographs taken at a tube voltage of 70 kV were suitable for checking internal porosity of cast titanium with different thickness. Fig. 4 shows a radiograph of a cast titanium metal framework taken at 70 kV and 1.5 s. A small pore that might be a source of fracture during habitual use (insertion and removal of dentures) can be seen in the left I-bur. The end of the left molar lingual clasp also contained some tiny pores that might lead to a fracture with lengthy usage. These bars and clasps are approximately 2.0-3.5 mm thick. The radiograph also indicated that the major connector has several pores which might not be critical for the breakage of metal framework during long term usage.

Another issue that should be considered is the different density levels caused by the shape and angle of the complicated metal framework as it is placed on the occlusal film. The cast titanium discs (Fig. 1) used in this study were placed directly on the occlusal film, leaving no space between the titanium disc and film. Therefore, the attenuated X-rays passing through the discs exposed the film immediately after penetration. When taking a photograph of cast titanium framework, some spaces (air gaps) are present between the framework and occlusal film (subject-film distance) due to the shape of the framework (a large space under the palatal plate exists in Fig. 4). The subject-film distance (air gap) enlarges the radiographic image of the subject and affects its density level and contrast due to the scattered radiation.[21,22] The shape of metal framework also leads to geometric distortion on the radiograph. Thus, it might take several radiographs to obtain one optimal radiograph that will detect internal porosity in different portions of the cast titanium framework. In any case, most internal porosity can be found if the radiograph is inspected carefully.

Conclusions

The results of this study indicated that the use of dental X-ray unit and occlusal film are useful for the inspection of internal porosity in titanium castings. The use of lower tube voltage and a longer exposure time is appropriate to clearly detect the internal porosity. Specifically, the results showed that a tube voltage of 70 kV covered a wide range of exposure times to produce certain density levels for each thickness of cast titanium disc.

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