RESEARCH ARTICLE

Use of tungsten sheet as an alternative for reducing the radiation dose behind the digital imaging plate during intra-oral radiography

¹Takehisa Nagasaka, ²Masahiro Izumi, ³Kenichi Gotoh, ³Tsutomu Kuwada, ¹Yoshitaka Kise, ⁴Akitoshi Katsumata and ¹Eiichiro Aji

¹Department of Oral and Maxillofacial Radiology, Aichi-Gakuin University School of Dentistry, Nagoya, Japan; ²Department of Dentomaxillofacial Diagnosis and Treatment, Kanagawa Dental University, Yokosuka, Japan; ³Division of Radiological Technology, Dental Hospital, Aichi-Gakuin University, Nagoya, Japan; ⁴Department of Oral Radiology, Asahi University School of Dentistry, Hozumi, Japan

Objectives: To verify the use of tungsten sheet as an alternative to lead foil for reducing the radiation dose behind storage phosphor plates (SPPs).

Methods: At six sites (incisor, canine, and molar sites in both the maxilla and mandible) in a head phantom, radiation doses were initially measured behind conventional film packets containing two films and a lead foil. At the same sites, radiation doses were also measured behind packets containing only SPPs. Thereafter, the same dose measurements were performed with shielding materials (lead foil or tungsten sheet) within the packets. These doses were defined as behind doses.

Results: There were no differences in the mean behind doses between the conventional film packets and the SPP packets without shielding materials for any of the six sites examined. The behind doses were reduced by both lead foil and tungsten sheet, with significant differences in all sites when compared with no shielding. Lead foil reduced the behind dose of the SPP packet to 37.6% on average, while tungsten sheet reduced the behind dose to less than 20% in all of the sites examined, with an average of 14.7%.

Conclusions: Tungsten sheet appeared to be effective as an alternative shielding material, sufficiently reducing the doses behind the SPP packets to less than 20% when compared with sheetless packets in all of the six sites examined.

Dentomaxillofacial Radiology (2019) **48**, 20180161. doi: [10.1259/dmfr.20180161](https://doi.org/10.1259/dmfr.20180161)

Cite this article as: Nagasaka T, Izumi M, Gotoh K, Kuwada T, Kise Y, Katsumata A, et al. Use of tungsten sheet as an alternative for reducing the radiation dose behind the digital imaging plate during intra-oral radiography. *Dentomaxillofac Radiol* 2019; **48**: 20180161.

Keywords: radiography, dental, digital; tungsten; radiation dosage; radiation protection

Introduction

The radiation dose behind a conventional intra-oral film packet is reduced by a lead foil (atomic number: 82) included in the packet.^{1–5} The direct shielding effect has been estimated in film packets with approximately 70- μ m-thick lead foil, indicating an average reduction of 77 and 56% of the primary beam at 60 and 90 kV, respectively.⁵ This shield is also effective in reducing a

patient's finger dose when a film-holding device with X-ray indicator is not used. Although exposure is generally reduced in recently popularized digital intra-oral X-ray systems,⁶ lead shielding is not usually applied to these systems. Based on the "as low as reasonably achievable"⁷ principle, we should try to reduce the absorbed dose, especially for children. Only one report has emphasized the effect of lead foil used for two digital systems in reducing the absorbed dose of various

Correspondence to: Kenichi Gotoh, kenichi@dpc.agu.ac.jp

Received 24 April 2018; revised 08 June 2018; accepted 02 July 2018

organs.⁸ In this report, the absorbed dose in the selected organs was reduced to approximately 32% in a storage phosphor plate (SPP) and 59% in a complementary metal oxide semiconductor when lead foil was added behind the sensors. However, the direct effect of the lead foil was not evaluated just behind the sensors, simulating the finger position. Meanwhile, lead foil used outside the packet may directly contact the finger or oral tissues, which may have deleterious effects. Because inorganic lead is easily dissolved in human saliva,⁹ there is a risk of lead exposure if dental office staff who handle the films fail to change their gloves or wash their hands after film processing.¹⁰ Therefore, repeated use in this manner has a potential risk to patients, dentists, radiographic technicians or others who take radiographs or manipulate image processing.

In addition, because of concerns about environmental pollution, the use and disposal of lead is strictly restricted.^{11,12} Therefore, in various industries, tungsten (atomic number: 74) is commonly used as an alternative to lead.¹³ In the radiology field, many trials have been performed to replace lead with tungsten as a radiation protection material.^{14,15} Therefore, tungsten sheet may have a substitutional potential to replace lead foil in intra-oral radiography.

The purpose of the present study was to verify the use of tungsten sheet as an alternative to lead foil for reducing the radiation dose behind SPP sensors.

Methods and materials

A head phantom was used for all measurements (Figure 1a). This comprised a human adult dried skull with a normal dentition, and was covered with soft tissue-equivalent materials mimicking intra-oral soft tissues and facial skin. A finger-like fixation tool was also equipped to the phantom.

Conventional dental film packets (INSIGHT, Carestream Health, Inc., NY) and SPP packets (Flat Bag, Flat Co., Kobe, Japan) containing an SPP (YCR Imaging Plate, Yoshida Dental Mfg., Co., Ltd., Tokyo, Japan) were set at six different sites (the incisor, canine, and molar sites in both the maxilla and mandible), and exposed by a dental X-ray machine with a circular collimator (MaxiX, J. Morita Mfg. Corp, Kyoto, Japan) according to the settings recommended by the manufacturer (Table 1). The tube voltage and current were fixed at 60 kV and 7 mA, respectively. The dental film packet, which was also in our ordinary examinations, contained two films and a 72- μ m-thick lead foil. The SPP packet consisted of inner and outer sacks sliding against each other and the non-exposure side was made of transparent material (Figure 2). The packets containing an SPP were first exposed without a shielding material. Thereafter, they were exposed with two types of shielding materials: lead foil used in the aforementioned film packet or tungsten sheet (X-ray Shield Plate, Flat Co., Kobe, Japan) that was recently made available for the intra-oral SPP

Figure 1 (a) Head phantom. The solid line arrow indicates the finger-like fixation tool. The dotted line arrow indicates the dosimeter used. (b) Dosimeter. The bidirectional arrow indicates the detector.

system (Figure 3). The 500- μ m-thick sheet (130 μ m lead equivalent), which was coated with a polyolefin film and could be disinfected with alcohol, was flexible and washable and consisted of 90% tungsten powder and 10% iron oxide. It also complied with the food sanitation law and the food additive standard in Japan. The total thickness of the film packet, comprising two films and a lead foil, and the SPP packet, comprising an SPP and tungsten sheet, was 1.2 and 1.7 mm, respectively, as measured with a vernier caliper. The doses behind the SPP packet were initially measured with only the SPP in the packet. Thereafter, lead foil or tungsten sheet was placed behind the SPP within the packet.

A high sensitivity radiofrequency dosimeter (RaySafe X2, Unfors RaySafe, Bilodal, Sweden) was used to measure the doses behind the film and SPP packets, and these were defined as behind doses. This dosimeter was connected to a base unit with a display on which we could see the measurement results immediately after exposure (Figure 1b). The size was 14, 22, and 79 mm in thickness, width, and length, respectively, and the weight was 42 g. Based on the specifications, dose detection ranged from 1 nGy to 9999 Gy within a tube voltage range between 40 and 150 kV, with the measurement error estimated to be 5% or 5 nGy. The detector part of the dosimeter was fixed adjacent to the film or SPP packet with the finger-like tool of the

Table 1 Patient entrance doses (mGy) and exposure conditions

	Maxilla			Mandible		
	Incisor	Canine	Molar	Incisor	Canine	Molar
DRL	1.3	1.6	2.3	1.1	1.1	1.8
Conventional film system	0.9	1.1	1.5	0.6	0.7	1.1
	(0.20 s)	(0.25 s)	(0.32 s)	(0.13 s)	(0.16 s)	(0.25 s)
Digital system	0.6	0.7	0.9	0.4	0.5	0.7
	(0.13 s)	(0.16 s)	(0.20 s)	(0.08 s)	(0.10 s)	(0.16 s)

DRL, diagnostic reference level in Japan.
Exposure times are given in parentheses.

phantom and exposed five times for each site. The resultant values were averaged and 95% confidence intervals were calculated.

Before measuring the behind doses, patient entrance doses (PEDs) were measured to verify the validity of the exposure conditions that were used in our clinics. The same dosimeter used for the behind doses was set at the edge of the X-ray unit cone and exposed three times at the conditions of each sites, and the absorbed doses measured were averaged. The focus to skin distance was set to 23 cm. Consequently, the exposure conditions were verified to be adequate because the doses appeared to be lower than the diagnostic reference level in Japan¹⁶ (Table 1).

Statistical analysis

Statistical analysis was carried out using SPSS statistics software v. 22.0 (IBM Corporation, NY). Two-sided unpaired *t*-test was applied for the comparison of behind doses. A *p* value less than 0.05 was considered to be statistically significant.

Figure 2 View of an SPP packet from the non-exposure side. A tungsten sheet is visible through the transparent cover indicating the non-exposure side. SPP, storage phosphor plate.

Results

There were no differences in the mean behind doses between the film packet with lead foil and the SPP packet without a shielding material for any of the six sites examined (Table 2). The behind doses of the SPP packets were reduced by both lead foil and tungsten sheet, with significant differences when compared with those without shielding materials in all sites examined. Lead foil reduced the behind dose of the SPP packets to 37.6% on average, while tungsten sheet reduced the behind dose to less than 20% in all of the sites examined, with an average of 14.7%.

Discussion

Recently, digital systems have gradually replaced conventional film-based systems in intra-oral radiography. Although the exposure conditions are considered to be relatively low in digital systems when compared with conventional systems,⁶ a shielding material, such

Figure 3 Schematic drawing of exposure setting with a shielding material. SPP, storage phosphor plate.

Table 2 Mean dose behind film or SPP sensor (μGy)

	Maxilla			Mandible		
	Incisor	Canine	Molar	Incisor	Canine	Molar
Conventional film packet containing two films and a lead foil	119.3 (109.9–128.8)	51.9 (40.4–63.4)	72.1 (58.9–85.2)	52.5 (49.1–55.9)	51.7 (43.9–59.6)	67.5 (60.3–74.8)
SPP packet containing solely an SPP	114.0 (93.2–134.7)	55.7 (34.1–77.3)	65.7 (46.2–85.2)	44.4 (33.9–54.9)	38.8 (32.6–45.0)	48.9 (35.0–62.8)
SPP packet containing an SPP and a lead foil	34.8** (26.6–43.0) 30.5%	19.5* (12.9–26.0) 35.0%	28.7* (24.9–32.4) 43.7%	14.0*** (13.6–14.3) 31.5%	15.9*** (15.7–16.2) 40.0%	22.0* (21.9–22.0) 45.0%
SPP packet containing an SPP and a tungsten sheet	14.6*** (13.3–16.0) 12.8%	7.6** (7.1–8.1) 13.6 %	9.4*** (8.7–10.0) 14.3%	5.0*** (4.9–5.2) 11.3%	7.7*** (7.2–8.1) 19.8%	7.9*** (6.9–8.9) 16.2%

SPP, storage phosphor plate.

Statistical significance comparing to the values of SPP packet solely with SPP with *: $p < 0.05$, **: $p < 0.01$ and ***: $p < 0.001$.

Values in parentheses: 95% confidential interval.

Bold letter: percentage rate to the value of SPP only.

as lead foil in a film packet, is not usually applied in digital systems. Therefore, it is worthwhile to examine the dose behind the imaging plate and to verify the use of shielding materials in digital intra-oral systems.

Since the absorbed dose can alter depending on the exposure conditions, their validity should be verified to adequately apply the results to a clinical setting. Therefore, the PED for the exposure condition that is typically used in our practice was tested before measuring shielding effects. Consequently, the PEDs used in the present study were verified to be adequate because they all appeared to be lower than the diagnostic reference level of intra-oral radiography in Japan.¹⁶

The lead foil in a dental film packet is considered to have two roles.^{1,2,5,17–19} One is to reduce the absorbed dose in the tissues behind the film packet, and the other is to prevent the back scatter radiation from such tissues to maintain image quality. The doses behind the SPP packets without shielding materials did not differ from those behind film packets with lead foil. This result suggests that the SPP itself has an equivalent reduction effect to the use of a film packet with lead foil. Even with this result, however, the necessity of shielding materials cannot be denied, based on the “as low as reasonably achievable” principle. According to the manuscript by Araki *et al.*,⁵ the international standard 3665 (ISO 3665) published in 1976, which we can no longer obtain because of revision and withdrawal, states that a backing lead foil no less than 50- μm -thick or some other flexible material with equivalent X-ray attenuation characteristics is required when measured at 90 kV. In their manuscript, they concluded that approximately 70- μm -thick lead foil attenuated the primary beam by 77% at 60 kV. Although the actual numerical value of appropriate thickness is not described in the newly-published ISO 3665 in 2016,²⁰ a 500- μm -thick tungsten sheet (130 μm of lead-equivalent thickness) was considered to provide a sufficient shielding effect. In fact, it reduced the behind dose by more than 80% when compared

with those without shielding. Comparing the shielding effects for the SPP system, the tungsten sheet showed approximately twice effect of the lead foil. This would be attributed to twice in lead-equivalent thickness of the tungsten sheet. Nejaim *et al* reported on the effect of lead foil in digital intra-oral systems for reducing various organ doses.⁸ Using a thermo-luminescent dosimeter, they determined the absorbed doses in various organs by intra-oral full-mouth radiography. Consequently, lead foil reduced the doses to approximately 32% in the SPP system. Although the resultant values cannot be directly compared with each other, our results support their findings in the verification of shielding effects by lead foil in the SPP system. A rectangular collimator would contribute to further reduction of absorbed dose.

As for the shielding effect of scattered radiation, Price stated that 65- μm -thick lead foil could reduce scattered radiation, but it could not be detected.^{17,18} Moreover, in ISO 3665 (2016),²⁰ the following manufacturer specifications for intra-oral radiographic film and film packets can be found; “lead foil of 0.038 mm or equivalent material provides protection from back scatter radiation to allow 19 lp mm^{-1} . Thicker foils can be used but do not provide any significant improvement in image quality and shielding”. Accordingly, tungsten sheet can sufficiently protect against scattered radiation from tissues behind the packet. Araki *et al*¹⁹ stated that lead foil itself causes scattered or secondary radiation and affects film speed and resolution, although it also protects the film against scattered radiation from tissues behind the film and results in improved resolution. The effects should be evaluated in future studies because the lead-equivalent thickness of tungsten sheet is approximately twice that of lead foil.

Although Nejaim *et al*⁸ also verified the use of lead foil for the SPP system, their technique forces us to directly contact the lead foil with oral soft tissue or with the finger when using a CMOS sensor. Even

when using a packet for SPPs, the foil directly touches the finger during packing and image processing. The toxicity of lead is well-known and the use of lead has been restricted to electrical and electronic equipment.¹² Therefore, tungsten sheet has a potential use in intra-oral radiography because it has already been applied to various fields, as there are no definitive hazards.¹³ Although tungsten sheet has been commercially available, there are some problems to be considered before use in the clinical setting. The thicker 1.7 mm packet may be uncomfortable for patients during image exposure. The ISO recommends a film packet thickness below 2.0 mm.²⁰ Although the SPP packet with the tungsten sheet did not exceed this recommendation, patient discomfort should be evaluated in future research. Another disadvantage is the relatively high cost of tungsten. However, the sheet used in this study could be used multiple times, which may solve this problem.

References

1. Poyton HG, Pharoah MJ. *Principle of radiographic technique: the X-ray film and film processing*. Oral Radiology. Toronto, BC: Decker Inc; 1989. pp. 23–6.
2. Goaz PW, White SC. X-ray film, intensifying screen, and grids. In: Goaz PW, White SC, eds. *Oral Radiology: Principles and interpretation*. St Louis, MO: Mosby-Year Book Inc; 1994. pp. 79–96.
3. Havukainen R, Servomaa A. Characteristic curves of dental x-ray film. *Oral Surg Oral Med Oral Pathol* 1986; **62**: 107–9. doi: [https://doi.org/10.1016/0030-4220\(86\)90081-2](https://doi.org/10.1016/0030-4220(86)90081-2)
4. Bourgeois M, Wood RE, Pharoah MJ. Reducing transmitted radiation in dental radiography. *Health Phys* 1992; **62**: 546–52. doi: <https://doi.org/10.1097/00004032-199206000-00007>
5. Araki K, Kanda S. Radiological characteristics of lead foils in dental film packets: analysis of components and shielding effect. *Dentomaxillofac Radiol* 1992; **21**: 21–5. doi: <https://doi.org/10.1259/dmfr.21.1.1397446>
6. Berkhout WE, Beuger DA, Sanderink GC, van der Stelt PF. The dynamic range of digital radiographic systems: dose reduction or risk of over exposure? *Dentomaxillofac Radiol* 2004; **33**: 1–5. doi: <https://doi.org/10.1259/dmfr.40677472>
7. The I. recommendations of the International Commission on Radiological Protection. ICRP publication 103. *Ann ICRP* 2007; **37**(2-4):1-3322007;.
8. Nejaim Y, Silva AIV, Brasil DM, Vasconcelos KF, Haiter Neto F, Boscolo FN. Efficacy of lead foil for reducing doses in the head and neck: a simulation study using digital intraoral systems. *Dentomaxillofac Radiol* 2015; **44**: 20150065. doi: <https://doi.org/10.1259/dmfr.20150065>
9. Tsuji LJS, Fletcher GG, Nieboer E. Dissolution of lead pellets in saliva. A source of lead exposure in children. *Bull Environ Contam Toxicol* 2002; **68**: 1–7. doi: <https://doi.org/10.1007/s00128-001-0211-y>
10. Tsuji LJ, Wainman BC, Jayasinghe RK, Van Spronsen E, Nieboer E. Foil backing used in intraoral radiographic dental film. A source of environmental lead. *J Can Dent Assoc* 2005; **71**: 35–8.
11. Lead laws and regulations [home page on the internet]. United States environmental protection agency. 2017. Available from: <https://www.epa.gov/lead> [updated 2017 August 30].
12. European Parliament and the Council of the European Union. Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment. 2011. Available from: <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32011L0065>.
13. Substitute for lead. Information on tungsten: sources, properties and uses [homepage on the internet]. <http://www.itia.info/a-substitute-for-lead.html>. Available from: <http://www.itia.info/a-substitute-for-lead.html>.
14. McCaffrey JP, Mainegra-Hing E, Shen H. Optimizing non-Pb radiation shielding materials using bilayers. *Med Phys* 2009; **36**: 5586–94. doi: <https://doi.org/10.1118/1.3260839>
15. Monzen H, Tamura M, Shimomura K, Onishi Y, Nakayama S, Fujimoto T, et al. A novel radiation protection device based on tungsten functional paper for application in interventional radiology. *J Appl Clin Med Phys* 2017; **18**: 215–20. doi: <https://doi.org/10.1002/acm2.12083>
16. Japan Network for Research and Information on Medical Exposure (J-RIME). Japan DRLs 2015 for dental intraoral radiography in diagnostic reference levels based on latest surveys in Japan. 2015.
17. Price C. An evaluation of lead foil in dental X-ray film packets. 1. Factors affecting the intensity of back-scattered radiation and the effect of this radiation on radiographic contrast when density is allowed to increase. *Br Dent J* 1972; **133**: 300–4. doi: <https://doi.org/10.1038/sj.bdj.4802911>
18. Price C. An evaluation of lead foil in dental X-ray film packets. 2. The effect of back-scattered radiation on radiographic contrast when the density is maintained at an optimum level. *Br Dent J* 1972; **133**: 343–6. doi: <https://doi.org/10.1038/sj.bdj.4802917>
19. Araki K, Kanda S, Toyofuku F. A study of the effects of lead foil in dental X-ray film packets on radiographic image quality. *Dentomaxillofac Radiol* 1993; **22**: 179–82. doi: <https://doi.org/10.1259/dmfr.22.4.8181643>
20. International Organization for Standardization (ISO). *ISO 3665: 2011(E). Photography – Intra-oral dental radiographic film and film packets- Manufacture Specification*. 3rd ed; 2011.

Based on the present results, we recommended to use the tungsten sheets for reducing the behind dose in plate-based digital radiography.

Conclusion

Tungsten sheet as an alternative shielding material could sufficiently reduce the radiation doses behind SPP packets to less than 20% when compared with those without tungsten sheets in all six sites examined.

Acknowledgements

We thank Angie Smaranda, M(Dent), from Edanz Group (www.edanzediting.com/ac) for editing a draft of this manuscript.