In Vitro Evaluation of Head and Neck Radiation Shields Used to Reduce Exit Dose

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Purpose: To determine the optimal thickness of protective oral radiation shields composed of an acrylic resin stent and a lead shield, which are used in head and neck radiotherapy to minimize undesired normal tissue radiomorbidity. ***Materials and Methods:*** Intraoral acrylic resin stents and lead shields of different thicknesses were inserted into a specially designed human mandible phantom with thermoluminescent lithium fluoride dosimeter chips (TLD-100) placed on the buccal and lingual sites and exposed to irradiation of different energies. Fifty-cGy irradiation was performed and TLD-100 dose measurements were obtained for each irradiation type, acrylic resin stent thickness, and lead shield thickness. ***Results:*** Acrylic resin stents with a 2-mm lead shield reduced 20% and 15% of the normal tissue dose for Co-60 and 6 MV X photon radiations, respectively, whereas the stents with a 4-mm lead shield achieved a higher reduction of the normal tissue dose (30% and 23% for Co-60 and 6 MV X photons, respectively). ***Conclusion:*** In protective oral radiation shields, acrylic resin stent thickness has little effect on the reduction of normal tissue dose, but lead shield thickness significantly effects the reduction of normal tissue dose. *Int J Prosthodont 2006;19:462–466.*

The management of patients with head and neck cancer is a complex process requiring a multidisciplinary approach, which presents a unique challenge to the clinician.[1,2] The goals of treatment in head and neck oncology are to eradicate the cancer, maintain adequate physiologic function, and achieve a socially acceptable cosmetic result. Radiotherapy is highly effective as a sole modality for early malignant lesions of the oral cavity.[3] The advent of teletherapy Co-60 units, followed by the invention of accelerators producing high-energy photons and electrons, made it possible to deliver potentially tumoricidal radiation doses, even to deep-seated neoplasms, without exceeding the tolerance of the skin and subcutaneous tissues. All treatment modalities, including surgery and radiotherapy, can produce disability. Surgery may interfere with speech, mastication, and deglutition. Radiotherapy can produce severe radiosequelas of xerostomia, dental caries, and mandibular necrosis.[2,4–8]

Mucosal weakening, soft tissue fibrosis, salivary gland disorders, and bone complications are postirradiation complications of the orofacial area, whereas with the onset of osteoradionecrosis, removing sequestra results in maxillary and/or mandibular bone loss, thus nullifying the advantage of radiotherapy.[9,10] The mandible, with its thick cortical bone and thin mucosa, is a prime target for refractory radiation osteopathy because of the compromised blood supply. The onset of osteonecrosis causes prolonged pain and eating difficulties, making oral management, such as postradiotherapy dental treatment, extremely difficult.[11,12] In the evaluation of osteoradionecrosis for mandibular bone, the end point is pathologic fracture,[13] similar to that of the rib and femoral head. The minimum tolerance dose (TD 5/5), which is the dose of radiation that could cause no more than a 5% severe complication rate within 5 years posttreatment, is

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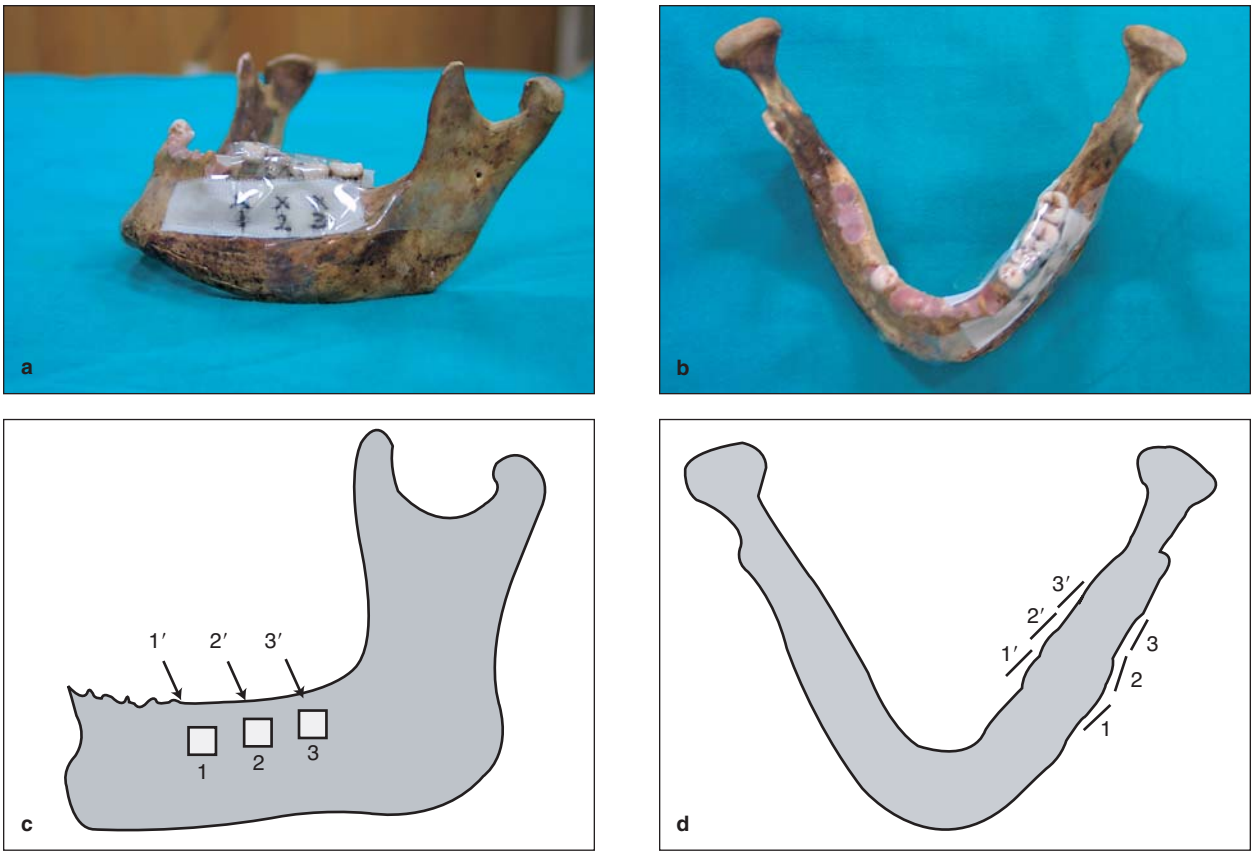


Figs 1a to 1d **(a)** Mandibular assembly without acrylic resin stent for measurement of entry and exit radiation doses (lateral view). TLD-100 chip placement sites for entry and exit dose measurement. **(b)** Occlusal view of the mandibular assembly. **(c)** Schematic mandibular assembly with TLD-100 placements: 1 = entry dose; 1′ = exit dose; 2 = entry dose; 2′ = exit dose; 3 = entry dose; 3′ = exit dose. **(d)** Schematic occlusal view of the mandibular assembly.

50 Gy for bone; whereas the maximum tolerance dose (TD 50/5), which is the dose of radiation that could cause up to a 50% severe complication rate within 5 years posttreatment, is 65 Gy for bone. Therefore, various radiotherapy prostheses aimed to reduce or prevent complications and improve the effectiveness of irradiation were developed. Inoue et al[14] in 1996 and Taniguchi[15] in 2000 reported the use of acrylic resin and lead plate in modern radiotherapy prostheses.

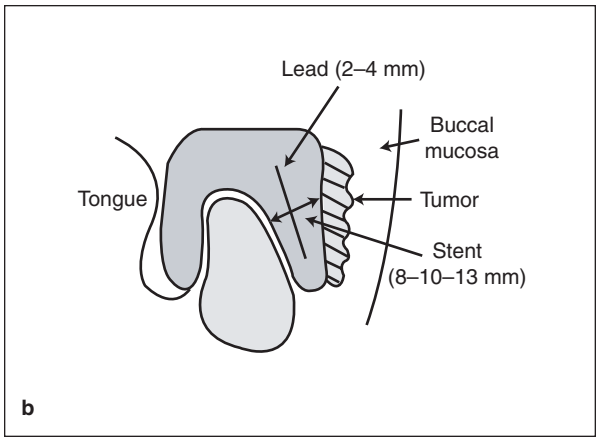
Radiotherapy prostheses, all of which can be fabricated by a maxillofacial prosthodontist upon request by the radiation oncologist, can be classified as spacers, shields, carriers, protectors, or molds (a carrier combined with a shield), depending on the reason for the request and the treatment objective.[14,15]

Determining how thick protective acrylic resin stents and complementary high-energy radiation-reducing lead shields should be for different irradiation types in head and neck radiotherapy is important in minimizing normal tissue morbidity and increasing patients' overall quality of life. Although the dose-reducing effect of stents in the mandible has been experimentally and clinically examined,[16–18] more research is still needed.

This experimental study was conducted to determine the optimum thicknesses of protective acrylic resin stents and lead shields used in head and neck radiotherapy to minimize normal tissue morbidity for different irradiation energies using thermoluminescent lithium fluoride dosimeter chips (TLD-100) in a specially designed human mandible phantom.

Materials and Methods

TLD-100 chips (Harshaw TLD, Bicron) with a square-prism shape were placed on buccal and lingual left mandibular premolar and molar sites with 2- or 4-mm-thick lead shields with an acrylic resin stent in a specially designed human mandible phantom, which was surrounded with water to simulate soft tissue density. A model buccal tumor was irradiated with or without acrylic resin stents of 8, 10, and 13 mm thickness by Co-60 gamma (Theratron 780, Nordion), 6 MV x-ray (Philips SL-25), and 8 MeV electron beam (Philips SL-25) (Figs 1 and 2). TLD-100 chips were read by a Victoreen 2800 TLD reader (Victoreen), and the ratio of the average values for gingivomandibular and teeth



Figs 2a and 2b **(a)** Mandibular assembly with acrylic resin stent and lead shield cover. **(b)** Schematic representation of the stent with lead shield.

entry/exit dose measurements with and without acrylic stents was recorded (Fig 1). As shown in Figs 1c and 1d, the average entry dose and exit doses were calculated according to the formula (1 + 2 + 3) / 3 and (1′ + 2′ + 3′) / 3 where 1, 2, 3 and 1′, 2′, 3′ are the locations of TLD-100 measurements.

In the preparation of the protective acrylic resin stents, an impression was made of the human mandible phantom with an impression tray and irreversible hydrocolloid (Palgat, Plus Quick, 3M ESPE). The casts were used to obtain custom trays. The trays were then checked for proper fit and a final impression was made with a medium-viscosity additional silicone material (Coltene-Whaledent). Wax models of the stents were made with the lead shield (2 or 4 mm thick) in the proper position (Fig 2). The stents were made of heat-polymerized acrylic resin (Meliodent Bayer) of 3 different thicknesses (8, 10, and 13 mm), and arranged on the planned buccal tumor site on the left premolar and molar areas. Each of the 6 TLD-100 chips was tightly packed and placed on buccal and lingual mandibular sides (3 on each side), with an acrylic stent and a 2- or 4-mm lead shield placed buccally. Fifty-cGy irradiation was performed for each, with an irradiation field size of 4 × 4 cm at 80-cm source-skin distance (SSD) for Co-60, 100-cm SSD for 6 MV X, and 95-cm SSD for 8 MeV electron beams perpendicularly with and without the stent plus lead shield. Measurements were repeated 3 times with 3 different energies, consisting of Co-60 gamma rays, 6 MV x-rays, and 8 MeV electron beams for 2- and 4-mm lead shields and 3 different stent thicknesses. Data of the entry and exit doses with different radiation prosthesis shields were calculated for statistical significance using the Mann-Whitney test and Kruskal-Wallis test with SPSS for Windows Release 13. Statistical significance was set at $P \leq .05$.

Results

The results of the 6 MV X and Co-60 gamma photon irradiation measurements in relation to acrylic resin stent thickness revealed a 1% reduction of normal tissue dose per 2 to 3 mm of difference in thickness, while the thickness of the lead shield mounted during acrylic stent preparation was significantly associated with normal tissue dose reduction for photons.

A 2-mm lead shield placed onto the protective acrylic resin stents resulted in 20% and 15% normal tissue dose reduction for Co-60 and 6 MV X photon radiations, respectively, whereas stents with 4-mm lead shields achieved a higher normal tissue dose reduction of 30% and 23% for Co-60 and 6 MV X photons, respectively (Table 1).

Differences in stent thickness are more important in 8 MeV electron beam therapy than in Co-60 and 6 MV X photon therapies (Table 1). In 8 MeV electron beam irradiation, 2 to 3 mm of stent thickness difference without an additional lead shield caused only 3% minimal normal tissue dose reduction, whereas in 8 MeV electron irradiation, a 2-mm lead shield plus a stent resulted in 85% to 91% normal tissue dose reduction, compared to 98% for a 4-mm lead shield plus a stent (Table 1).

The statistical differences between groups are shown in Table 2.

Discussion

Head and neck cancers treated with radiotherapy almost always bear the risk of serious radiosequelas, of which xerostomia, caries, and osteoradionecrosis are the most widely reported.[5–8] In head and neck radiotherapy for buccal tumors, photons and electrons may be used as

Table 1 Entry and Exit Radiation Dose TLD-100 Measurements for Co-60, 6 MV X, and 8 MeV Electron Beams for Different Acrylic Resin Stent and Lead Shield Thicknesses (±SD)

	Co-60 gamma		6 MV X		8 MeV electron	
Stent /lead shield thickness/dose	Dose with stent/ without stent (%)	Dose reduction rate (%)	Dose with stent/ without stent (%)	Dose reduction rate (%)	Dose with stent/ without stent (%)	Dose reduction rate (%)
8 mm						
2 mm						
Entry	82 (±0.59)	18 (±0.59)	87 (±0.43)	13 (±0.43)	15 (±0.45)	85 (±0.45)
Exit	85 (±0.53)	15 (±0.53)	88 (±0.64)	12 (±0.64)	9 (±0.14)	91 (±0.14)
4 mm						
Entry	72 (±0.62)	28 (±0.62)	79 (±0.42)	21 (±0.42)	2 (±0.06)	98 (±0.06)
Exit	74 (±0.55)	26 (±0.55)	79 (±0.41)	21 (±0.41)	2 (±0.30)	98 (±0.30)
10 mm						
2 mm						
Entry	81 (±0.59)	19 (±0.59)	86 (±0.60)	14 (±0.60)	12 (±0.20)	88 (±0.20)
Exit	85 (±0.48)	15 (±0.48)	87 (±0.55)	13 (±0.55)	3 (±0.30)	97 (±0.30)
4 mm						
Entry	71 (±0.36)	29 (±0.36)	78 (±0.48)	22 (±0.48)	2 (±0.06)	98 (±0.06)
Exit	74 (±0.54)	26 (±0.54)	79 (±0.36)	21 (±0.36)	2 (±0.08)	98 (±0.08)
13 mm						
2 mm						
Entry	80 (±0.63)	20 (±0.63)	85 (±0.64)	15 (±0.64)	9 (±0.38)	91 (±0.38)
Exit	82 (±0.49)	18 (±0.49)	85 (±0.45)	15 (±0.45)	2 (±0.07)	98 (±0.07)
4 mm						
Entry	70 (±0.33)	30 (±0.33)	77 (±0.43)	23 (±0.43)	2 (±0.06)	98 (±0.06)
Exit	72 (±0.26)	28 (±0.26)	77 (±0.50)	23 (±0.50)	2 (±0.18)	98 (±0.18)

Table 2 *P* Values of Exit Doses with Different Radiation Prosthesis Shields

		P		
Radiation prosthesis shield	Statistical test	Co-60	6 MV X	8 MeV electron
8-mm stent + 2-mm lead vs 8-mm stent + 4-mm lead	Mann-Whitney	.05	.05	.04
10-mm stent + 2-mm lead vs 10-mm stent + 4-mm lead	Mann-Whitney	.05	.05	.04
13-mm stent + 2-mm lead vs 13-mm stent + 4-mm lead	Mann-Whitney	.05	.05	.63
2-mm lead + 8-mm stent vs 2-mm lead + 10-mm stent vs 2-mm lead + 13-mm stent	Kruskal-Wallis	.06	.05	.02
2-mm lead + 8-mm stent vs 2-mm lead + 10-mm stent vs 2-mm lead + 13-mm stent	Kruskal-Wallis	.06	.11	.84

external curative radiation types. In this study, for the selected buccal tumor localization, Co-60 gamma, 6 MV X, and 8 MeV electron therapies were evaluated for the absorbed dose beyond desired treatment volume that may pose the risk of radiomorbidity.

Ionizing radiation affects various tissues in the oral cavity. In this experimental study, protective acrylic resin stents with lead shield optimization for both immobilization and radiomorbidity protection were studied in terms of stent thickness and lead shield thickness for different radiation types and energies.

Protective acrylic resin stents not only immobilize the dose-reducing malleable lead shields, but also hinder the range of backscattered electrons from the lead shields, which can cause localized radiation overdose within the stent to the normal tissue. Although 3-mm stent thickness was suggested in the study conducted by Reitemeier et al,[16] higher energies were used in this study and required thicker stents of 8 to 13 mm to absorb the electrons scattered from the lead shields. However, intraoral volume constraints may necessitate patient-tailored thickness adjustments.

The effect of stents in reduction of the radiation dose to the mandible has been examined experimentally and clinically, and a reduction of about 60% to 70% was found for a stent thickness of 10 mm in a low-energy brachytherapy study by Fujita et al.[17,18] According to our results, for example, a 60-Gy total treatment dose decreases to 49.2 Gy in the exit with a 2-mm lead shield and 43.2 Gy with a 4-mm lead shield for Co-60 gamma rays, resulting in 18% and 28% dose reduction rates, respectively. This significant reduction of the exit dose results in a total minimal tolerated dose (TD 5/5) reference below the mandibular osteoradionecrosis dose that may lead to pathologic fracture of the bone.

However, in this study of 3 different external therapy radiation energies and lead shield thicknesses, it was found that lead shield thickness was more significant than acrylic resin stent thickness in reducing the dose absorbed by normal tissue and reducing the risk of osteoradionecrosis of the mandible.

Conclusion

Under the conditions of this study, the following conclusions can be drawn:

1. When the acrylic resin stent thickness is increased from 8 to 13 mm, the dose absorption of the acrylic stent with a 2-mm lead shield increases for Co-60 gamma, 6 MV X, and 8 MeV electron beams by 2%, 2%, and 6%, respectively.
2. When a 4-mm-thick lead shield is used, the dose absorption percentage of the 8- to 13-mm stents increases to 28% to 30%, 21% to 23%, and 98% for Co-60 gamma, 6 MV X, and 8 MeV electron beams, respectively.
3. For 8 MeV electrons, a 2-mm lead shield is sufficient for radiomorbidity prevention, but 6 MV X and Co-60 gamma beams require a thicker lead shield.
4. The use of a radiation shield with precisely individualized acrylic resin stents is crucial in head and neck cancer radiotherapy to overcome radiomorbidity in a clinical setting.

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