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The Effects of BID Length and Shape on the Surface Area and Volume of Tissue Exposed During Dental Radiography

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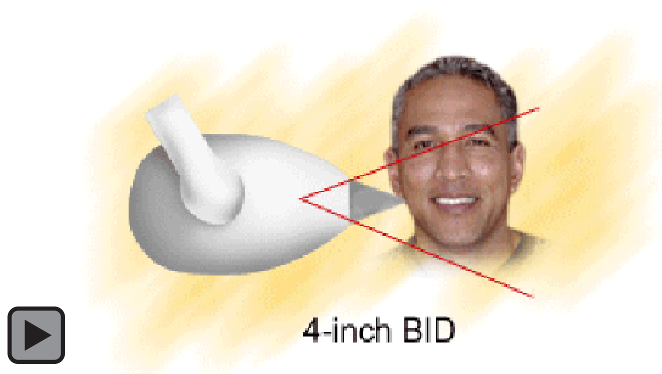

Abstract

Using projection geometry, algebraic formulas, and different beam indicating devices (BIDs), the surface area and volume of tissue exposed for a hypothetical patient was determined. Combinations of 4 BID lengths and shapes were used: 4-inch (10.2 cm.) pointed plastic, 8-inch (20.3 cm.) round plastic, 14-inch (35.6 cm.) round aluminum, and 14-inch (35.6 cm.) rectangular aluminum. As each subject BID was progressively lengthened and collimated, the area and volume of tissue exposed was reduced. The calculated area and volume of exposed tissue for the 14-inch rectangular aluminum open-ended lead-lined BID was 16.6 $cm.^2$ and 327.7 $cm.^3$, respectively. This represented 9% of the area and 8% of the volume of tissue exposed using the 4-inch round pointed plastic BID or a 91% (area) and 92% (volume) reduction in patient exposure.

Keywords: Dental radiology, collimation, BID length, projection geometry, x-radiation reduction

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Introduction

It is difficult to assess the potential damage from low levels of x-radiations similar to those found in diagnostic dental radiography. Only estimates are available and these are based on interpolated data from massive radiation exposures due to the industrial accidents or warfare. As a result, the dentist should use the concept of "as low as reasonably achievable" (ALARA) when instituting radiation protection procedures. The concept of ALARA is based on the assumption that all radiations can cause harm and, thus, any exposure to radiations should be kept as low as possible.

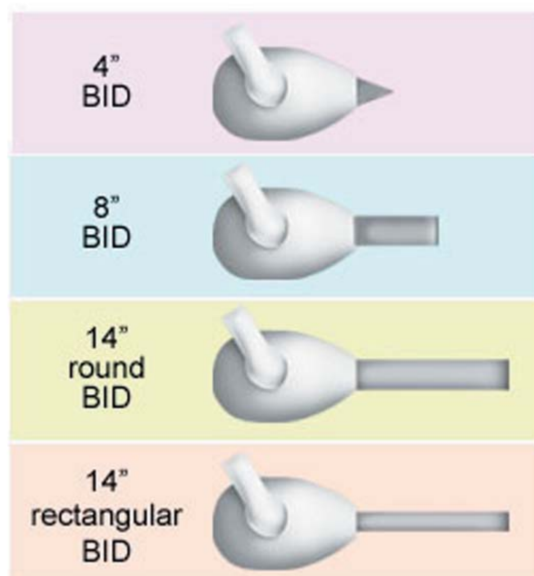
According to the American Dental Association[1], "the combination of proper collimation and extended source-patient distance (focal spot-to-film distance) will reduce the amount of radiation to the patient." Federal regulations[2] specify the entrance beam diameter at the patient's skin/face should be no greater than 7 cm (2.75-inch). This would be equal to a maximum entrance area of 38.5 cm^2. But, since the beam passes through the patient's head as an expanding field of radiation, the volume of tissue exposed would seem to be more important in determining relative risk of various lengths and shapes of BIDs. The regulations do not address the maximum volume of the tissue to be exposed or the critical organs in the head and neck area. Critical organs are those organs that are particularly vulnerable to developing potential late effects detrimental to the quality of life. The critical organs of the head and neck are the eyes, skin, bone marrow, thyroid, and salivary glands.

Purpose

The aim of this study was to use projection geometry to demonstrate the effects of shape and length on the surface area and volume of tissues exposed during dental radiography compared to the regulated maximum area of exposure.

Materials and Methods

Four x-ray beam indicating devices (BIDs) were selected including one each of the following: 4-inch (10.2 cm.) pointed plastic non lead-lined, 8-inch (20.3 cm.) round plastic open-ended non-lead-lined, 14-inch (35.6 cm.) round aluminum open-ended lead-lined, and a 14-inch (35.6 cm.) rectangular aluminum open-ended lead-lined. An 8" x 10" film cassette (Kodak[1] Lanex regular screen) and Kodak[1] T-Mat G film was used for all exposures.



The film cassette was placed on a flat surface and the beam was centered perpendicular to the film cassette. To ensure the film and the BID were perpendicular to each other, a right-angled T-square was utilized. Distances in inches were present on the T-square to ensure reproducible BID positioning. A centering position for the beam was marked on the cassette.

Each BID was used to expose 2 films at different distances, measured from the x-ray source to the end of the BID. For the first film, the distance between the end of the BID and the surface of the film cassette was 1 inch (representing the approximate average BID position for exposures of actual patients). The end of the tube should be positioned very closely to the patient's skin but in general clinical usage there is usually some separation between the face and the end of the BID. For consistency, we chose 1-inch distance to begin the tissue area and volume measurements. For the second film, the distance from the end of the BID to the film surface was 6 inches (representing the approximate exit size for a beam that had passed through a patient 5 inches in thickness). To assist in accuracy of measurements, an attempt was made to have approximately the same density for the exposed center of the beam. Exposure factors were changed as necessary to reflect distance differences between x-ray source and film surface. After completion of exposures, all exposed films were processed on the same day, using an Alphatek AX 700 automatic processor, with a 90 second processing cycle and temperature of 90° F. To ensure optimum processing conditions and optimum quality films, strict quality control was employed.

A total of 8 images were obtained. All measurements of exposed area on film were made utilizing the same measuring device. The volume of exposure was determined using the following formulas for the volume of a frustrum of a cone for round BIDs and volume of a frustrum of a pyramid for the rectangular BID. Formulas and constant values used are as follows:

- pi = 3.14
- Volume of the frustum of a cone = pi*(h/3)*((r*r)+(r*R)+(R*R))
- R or r = radius of entrance or exit measured on process film[3]
- Volume of the frustum of a pyramid = 1/3h(A + square root Aa + a)
- A or a = areas of entrance or exit[4]

Results

The results are presented in Table 1. The 4-inch BID had a beam entrance radius of 7.6 cm, which greatly exceeds the federal regulations for maximum diameter of 7 cm. The 8-inch BID also exceeded the federal standard. If the end of the BID was placed in contact with the skin, the skin diameter values for these tubes would be reduced. For consistency, we chose to begin measuring volume and area at 1 inch from the end of the BID. Both 14-inch BIDs had diameters that were less than the federal regulation value even at 1 inch from the end of the BID.

One observation not measured or recorded in Table 1 concerned the amount of scatter radiation. The BIDs that were not lead-lined demonstrated increased amounts of scatter radiation, which was observed as fogging beyond the periphery of the darkening due to the central beam. On the other hand, the lead-lined tubes had very little fogging beyond the sharp border of the exposed portion of the film.

Due to the rectangular shape of one of the 14-inch BIDs, "A" and "a" values for the frustrum of a pyramid were used instead of "R" and "r" values. The round pointed plastic tube exposed the largest volume of tissue for the hypothetical patient 5 inches thick. The 14-inch rectangular BID exposed the smallest volume. The 8-inch round and 14-inch round BID demonstrated intermediate values for volume.

There was a dramatic reduction in the volume of tissue exposed with progressively longer BIDs. The most reduction in exposed volume occurred with the 14-inch rectangular BID. The 14-inch rectangular BID exposed only 8.1% of the volume of tissue exposed by the 4-inch round non-lead lined pointed BID.

Table 1.

BID shape and length in centimeters (inches)	R = beam exit radius in centimeters (inches)	r = beam entrance radius in centimeters (inches)	Volume of exposed tissue in cubic centimeters (cubic inches)	Percentage of the exposed volume of the 4-inch round cone
10.2 (4") round	11.4 (4.5)	7.6 (3.0)	96.9 (246.2)	100.0%
20.3 (8") round	7.1 (2.8)	5.0 (2.0)	38.7 (98.3)	39.9%
35.6 (14") round	5.0 (2.0)	3.3 (1.3)	19.3 (48.9)	19.9%
35.6 (14") rectangular	A = 12.7 (5.0)	a = 6.6 (2.6)	7.8 (20.0)	8.1%

h = distance between entrance and exit film planes = 5 inches or 12.7 centimeters

Discussion

Because one of the 14-inch BIDs was rectangular, the formula values for this BID were "A" and "a" (areas) and not "R" and "r" (radii) in the formula for frustrum of a pyramid. The 14-inch tube rectangular volume was 8.1% of the volume exposed using 4-inch round cone. As BID length increases, the divergence of the collimated beam is reduced, and as a result, the diameter of the beam gets smaller. Use of lead-lined devices also decreased the divergence and scatter of the x-ray beam. With reduction in the size of the beam of radiation, the volume of exposed tissues and amount of exposure to critical organs is reduced. Figures 1-4 show effects of longer tubes and greater collimation on the volume of tissue exposed as indicated by the data in this study. Use of longer cones and greater collimation reduces volume of whole body exposure of x-ray machine operators due to scatter from patient. This would be a positive effect of long cone usage.

The inverse square law applies to various forms of electromagnetic energy. Briefly, it states that as the distance from the source of radiation to the object being irradiated increases, there is a decrease in the intensity of the beam. The inverse square law mandates an increase in exposure times with longer BIDs in order to have the same density in processed films. Faster, more sensitive conventional films and the recent introduction of digital radiology have offset this increase in exposure.

Conclusions

In summary the results indicated that as the BID length and collimation was increased, entrance and exit beam size decreased, and the calculated volume of tissues exposed decreased for the hypothetical 5-inch thick patient.

Based on the results of this study, the following recommendations can be made:

1. Long open-ended lead-lined BIDs reduce scatter radiation to patient and operator.
2. Rectangular BIDs are recommended over round BIDs because they produce the least amount of exposure to patients and personnel with increased image sharpness.
3. Short pointed plastic cones are not recommended for diagnostic dental radiography.

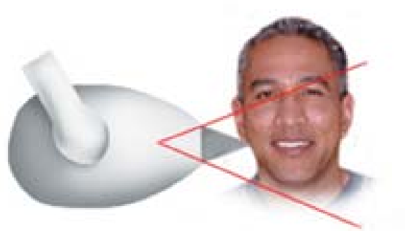


Figure 1. A 4-inch BID.

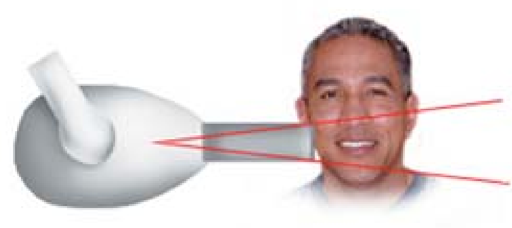


Figure 2. An 8-inch BID.

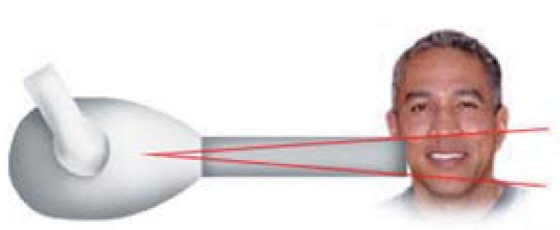


Figure 3. A 14-inch round BID.

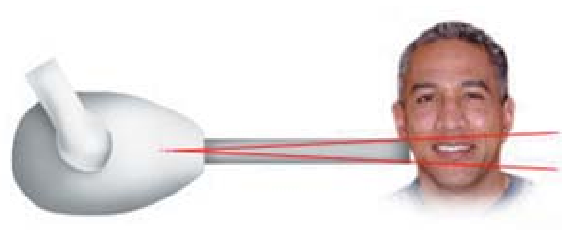


Figure 4. A 14-inch rectangular BID.

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