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IMAGE QUALITY AND RADIATION DOSE COMPARISON FOR INTRAORAL RADIOGRAPHY: HAND-HELD, BATTERY POWERED VERSUS CONVENTIONAL X-RAY SYSTEMS

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ABSTRACT

A hand-held, battery-powered dental intraoral x-ray system (60 kV, constant potential output) was compared to a conventional, wall-mounted intraoral x-ray system (70 kVp, self-rectified output) in terms of image quality, and patient and staff radiation doses.

The image quality comparison included quantitative measurements of image sharpness (resolution) and contrast.

Patient doses were compared using the FDA dental phantom and adjusting the radiation dose to obtain the same density on intraoral dental films.

Staff radiation doses were measured using personal dosimetry badges for dental facilities before and after introduction of the hand-held x-ray system allowing accurate comparison of staff doses with both systems under similar workloads and operating conditions.

Results for both image quality, and dose to patients and staff are provided.

INTRODUCTION

Hand-held, battery-powered x-ray units are coming into use in North America. Over 3,000 units are in use today in the U.S. in dental radiography, veterinary medicine, forensic, military, and research applications. Regulatory concerns have been expressed about the use of these devices including issues about image quality, patient dose, operator radiation dose from x-ray tube leakage and scatter, and the perception of these units using lower kilovoltage.

This paper compares the Nomad (Aribex, Orem, Utah) intraoral x-ray system to conventional, wall-mounted systems in terms of image resolution and contrast, the half-value layer (HVL) of the beam, patient dose, scattered radiation, x-ray tube leakage, and dose to the operators.

The authors apologize for the use of a brand name of a commercial product so frequently. At the onset of this project we were referring to this device as a "hand-held" device. However, other hand-held devices are coming into the market place. These new devices may vary significantly from the device evaluated.

MATERIALS AND METHODS

SYSTEMS COMPARED

The hand-held, intraoral x-ray system evaluated was the Nomad. For image quality and patient radiation dose purposes this unit was compared to Gendex GX-770 (Gendex Dental Systems, Lake Zurich, Illinois). The specifications for these systems are provided in Slide 8.

The Nomad is specifically designed as a hand-held x-ray device. Consequently, special design features have been incorporated including:

- Increased shielding around the x-ray tube
- Built-in, integral leaded acrylic shield to protect the user from backscattered radiation
- Shielded position indicating device (PID), or collimator.

METHODS

Calculated x-ray waveforms were compared. The kilovoltage waveform for the Nomad was modeled as a constant-potential waveform (Slide 10) with the average kilovoltage being that specified by the manufacturer, i.e., 60 kV.

The kilovoltage waveform was modeled as a single-phase waveform for the conventional system (Slide 10) with the peak kilovoltage of 70 kVp. A filter was added to the beam to produce a filtered waveform similar to that found in clinical practice.

Image resolution was measured using a Nuclear Associates 0.025-mm thick lead test pattern (#71412) with frequencies ranging from 1.5 to 20 c/mm. Kodak Insight E-F speed film was used for all images.

The contrast (density difference) was determined using the FDA dental phantom and measuring the density difference between two areas of the phantom.

The radiation exposure and HVL measurements were made with a Radcal Model 9010 dosimetry system with either a 6 cm^3 or 180 cm^3 ionization chamber. HVL measurements were made using type 1100 aluminum.

Scattered radiation was measured using a typical one-gallon milk jug filled with water to simulate the human head.

Staff dosimetry measurements were obtained for 18 facilities resulting in 422 reports for Nomad users and 122 reports for users of conventional x-ray equipment for a total of 546 individual staff dosimetry reports. Dose comparisons were carried out in four different ways: a) the percentage of dosimeters showing no measurable radiation; b) the average of all dosimeter readings; c) the average of all non-zero reading dosimeters; and d) the average of paired dosimeter measurements.

"Paired" dosimeter measurements means that staff dosimetry data was obtained from staff using a conventional, wall-mounted system before the introduction of the Nomad. Subsequently staff dosimetry ***from the same operators*** was obtained after the introduction of the Nomad. This resulted in 42 "paired" measurements, i.e., measurements for the same staff using different, conventional intraoral x-ray systems and then the Nomad. The data were from facilities using either D-speed film or digital imaging.

RESULTS

The average kilovoltage for the unfiltered, 70 kVp single phase waveform is 43 kV. With filtration added to meet FDA requirements (1.5 mm HVL at 70 kVp) the average kilovoltage is 56 kV. Consequently, the 60 kV average kilovoltage of the Nomad is higher than that of a filtered 70 kVp beam.

Image resolution is reduced for greater object to image distances, for a fixed focal spot to image distance. In other words, as the object is moved away from the film the resolution is decreased as in clear in Slide 11. When the object, or resolution test pattern, is in contact with the film the resolution is limited by the image receptor (film or digital receptor). The Nomad exhibits better resolution than the conventional system due to the differences in focal spot size (0.4 mm vs 0.6 mm, respectively). It should be noted that the Nomad was hand-held for these exposures, i.e., it was not mounted on a tripod or similar device.

The contrast or density difference was significantly higher (better) for the Nomad as compared to the conventional x-ray system. (Slide 12)

The HVLs of the two systems met the FDA minimum values of 1.5 mm Al at 70 kVp, with the conventional x-ray system having a slightly higher HVL.

Patient radiation doses were 153 mrad for the Nomad compared to 126 mrad for the conventional system. This 18% difference is well within the variability of patient doses from one unit to another regardless of type of x-ray system. The slightly lower dose for the conventional system is probably due to the slightly higher HVL.

However, it should be stressed that the dose-area product (roentgen-area product, RAP) is lower for the Nomad at 4.3 R-cm^2 compared to 4.9 R-cm^2 for the conventional system. This indicates that the absorbed radiation dose to the patient for the Nomad will be 14% lower than for the conventional system due to the fact that the irradiated area is smaller for the former compared to the latter.

The scattered radiation measured at 90° and 10 cm from the water-filled milk jug was lower for the Nomad at 0.089% of the entrance exposure compared to 0.153% for the conventional system. In other words, the scattered radiation for the Nomad is 58% of that for the conventional system, primarily due to the small irradiated area.

The maximum leakage radiation is specified by the FDA as 100 mR/hr at 1 meter. However, most x-ray tube leakage is on the order of 25 mR/hr or less at 1 meter. The measured leakage for the Nomad is 0.015% (0.00015) of that for an x-ray tube producing 25 mR/hr.

The results of the staff radiation dose measurements are shown in Slides 20-22. The percentage of dosimeters showing no measurable radiation (M, or 0 mrem) for Nomad users was 94.3% while that for the users of conventional x-ray systems was 77.9%.

The average monthly dose for all dosimeters from Nomad users was 0.051 mrem and 0.604 for users of conventional equipment. (Slide 20) In other words, Nomad users received about 8% of the radiation dose received by users of conventional equipment.

The average staff dose for those with the non-zero dosimeter readings was 0.901 mrem for the Nomad compared to 2.73 mrem for users of conventional intraoral x-ray systems. In this case, the average staff dose for Nomad users was 33% of that for users of conventional equipment.

The comparison of staff dosimetry for “paired” measurements removes many of the variables, e.g., work load, etc., from the data. The average monthly, paired staff doses for the Nomad users was 0.028 mrem compared to 0.786 mrem for those using conventional intraoral x-ray systems, a statistically significant difference at the $p = 0.01$ level. In other words, the average monthly dose for the Nomad users was 3.6% of that for users of conventional dental x-ray systems.

CONCLUSIONS

In conclusion, this study indicates that the resolution and contrast for the Nomad are superior to the Gendex x-ray system. In addition, the leakage and scattered radiation are lower for the Nomad compared to conventional, wall-mounted intraoral dental systems. The HVL meets the FDA requirements, with the Gendex having a slightly higher HVL than the Nomad. Both entrance radiation doses and the dose-area products for the two systems are similar.

Occupational doses are lower with the Nomad than with conventional intraoral x-ray systems. This is probably due to the tube shielding design (the Nomad is designed to be hand held and has significantly more shielding around the x-ray tube than a conventional system), the Nomad integral shield to protect the user from scattered radiation, and the shielded position indicating device (collimator).

Based on the results of this study, use of the Nomad dental intraoral x-ray system results in significantly lower staff doses compared to wall-mounted systems. Consequently, additional measures, e.g., use of lead aprons or stands, are not warranted.

Image Quality and Radiation Dose for Intraoral Radiography: Hand-Held (Nomad), Battery Powered vs. Wall-Mount X-Ray Systems

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- Our apologies for using the brand name of a commercial product so frequently
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- However, other hand-held devices are coming into the market place– these new devices may vary significantly from the device evaluated

Purpose

Compare Nomad intraoral x-ray systems to wall-mount systems in terms of—

- Image resolution
- Contrast
- Half-value layer (HVL)
- Patient dose
- Scattered radiation
- X-ray tube leakage
- Dose to operators

Background

- Hand-held units are coming into use in North America
- Several firms are manufacturing hand-held devices overseas and beginning to market these in the U.S.
- Over 3,000 units are in use today in the US in dental radiography, veterinary medicine, forensic, military, and research applications
- Regulatory concerns have been expressed about the use of these devices

Concerns

- Image quality
- Perception of lower kVp
- Patient dose
- Operator exposure from the x-ray tube and scattered radiation

Nomad Intraoral Dental System

Nomad is designed as a hand-held x-ray device

Special design features include—

- Increased x-ray shielding around the x-ray tube
- Built-in integral leaded acrylic shield to protect operator from backscatter
- Shielded position indicating device (PID) or cone

Comparison Units

Hand-held system—
Nomad
Aribex, Inc.
Orem, Utah

Wall-mount system—
GX-770
Gendex Dental Systems
Lake Zurich, Illinois

Specifications

	Nomad	Wall-Mount
Kilovoltage	60 (Constant Potential)	70 (Single phase)
mA	2.3	7
Typical exposure time (F-Speed Film) in sec	0.34	0.17
PID diameter (cm)	6	7
Source-to-cone tip (in)	8	8
Focal spot size (mm)	0.4	0.6

X-Ray Waveforms

Conventional– Alternating voltage output is 70 kVp

Average kilovoltage is approximately 56 kV

Constant potential generators (CPG), also known as DC, provide the same, constant kilovoltage

60 kV is 60 kV

Comparison of Waveforms

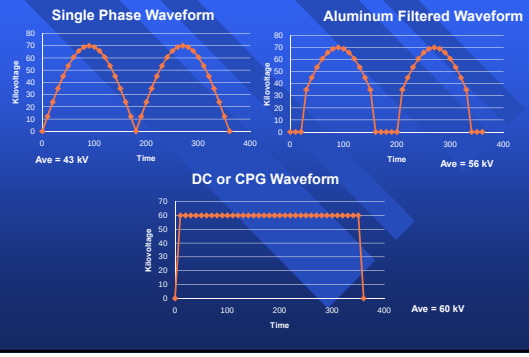


Image Resolution (cycles/mm)

	Contact	1 inch	2 inches	3 inches
Nomad	> 20	14	10	6
Wall-mount	> 20	13	6.5	6

At Various Object-to-Image Distances

Contrast (Density Difference)

	Density Difference
Nomad	0.55
Wall-mount	0.47

Half-Value Layer (HVL)

	HVL (mm of Al)
Nomad	1.92
Wall-mount	2.25

FDA limit 1.5 mm

Patient Entrance Exposure

	Exposure (mR)	RAP* (R-cm^2)
Nomad	153	4.3
Wall-mount	126	4.9

For Kodak Insight (E-F Speed) Film
Exposure difference = 18%, within typical variability
Exposure differences due to HVL differences
RAP = Roentgen-area-product , proportional to effective dose

Scattered Radiation

	% of Entrance Exposure
Nomad	0.089%
Wall-mount	0.153%

90° scatter at 10 cm from 1 gallon milk container
Nomad/Wall-mount = 0.58

X-Ray Tube Leakage

FDA maximum allowable leakage—
100 mR/hr at 1 meter

Nomad leakage—
Not measurable at 1 meter
(With 180 cm^3 chamber)

X-Ray Tube Leakage

Measurements made at 60 kV, 0.99 s*, at 5 cm (distance of hand on grip from x-ray tube)—
25 µR per exposure

Maximum permissible exposure to hand is 50,000 mR or equivalent of 2 million x-ray exposures

*Typical exposure 0.35 s

How Does Leakage Compare?

FDA maximum 100 mR/hr at 1 meter
Assume no more than 25 mR/hr at 1 meter

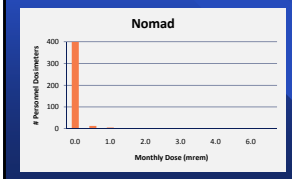
Leakage radiation for Nomad is
0.00015
that of wall-mount (based on 25 mR/hr)

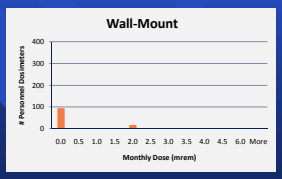
Dose to Operators

Retrospective dosimetry study
423 dosimetry reports for Nomad
122 dosimetry reports for wall-mount
Included 42 "Paired" reports, i.e., reports for same staff using wall-mount and then Nomad
All readings converted to monthly values

All Dosimeter Readings

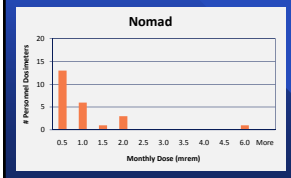
	n	% with "m" (0 mrem)	Average All (mrem)	SEM
Nomad	423	94.3	0.051	0.016
Wall-mount	122	77.9	0.604	0.138

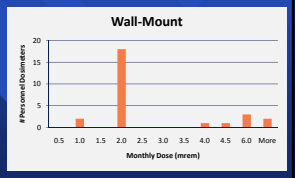




Non-Zero Dosimeter Readings

	n	Average (mrem)	SEM
Nomad	24	0.901	0.216
Wall-mount	27	2.73	0.418

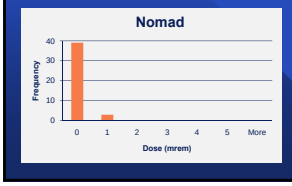


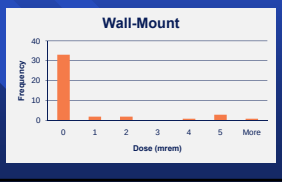


"Paired" Dosimeter Readings

	n	Average (mrem)	SEM
Nomad	42	0.028*	0.004
Wall-mount	42	0.786*	0.123

*Statistically significant difference at p = 0.01 level





Conclusions

	Nomad	Wall-Mount
Resolution	√	
Contrast	√	
HVL	Meets FDA	Meets FDA
Patient Dose	≅	≅
Scattered Radiation	√	
Leakage Radiation	√	

√ = Superior Performance

Conclusions

Occupational doses lower with Nomad than with wall-mount due to—

- X-ray tube shield design
- Integral scattered radiation shield
- Shielded PID

Conclusions

Use of Nomad dental intraoral x-ray system results in lower staff doses compared to wall-mount systems

Additional measures, e.g., use of stands or lead aprons, are not warranted

Contact Information

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