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Original Article

Comparison of radiation levels from computed tomography and conventional dental radiographs

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Background: With the increasing use of computed tomography (CT) in oral diagnosis and treatment planning, concern has been expressed about the high levels of radiation used, and the associated risks.
Objectives: The purpose of this study was to compare the radiation doses of facial CT scans with the radiation doses taking a lateral cephalometric radiograph, a panoramic radiograph (OPG), an occlusal film, and an intra-oral periapical radiograph.
Methods: An Alderson-Rando anthropomorphic phantom head was used for the analysis. Thirty-six lithium fluoride thermoluminescent dosimeters were placed in the phantom head in locations representing radiosensitive sites. Standard facial CT scans and conventional radiographs (lateral cephalometric, OPG, maxillary occlusal, intra-oral periapical) were then taken of the phantom head.
Results: The following radiation doses were measured: maxillo-mandibular CT scan, 2.1 mSv; maxillary CT scan, 1.40 mSv; mandibular CT scan, 1.32 mSv; lateral cephalometric radiograph, 0.005 mSv; OPG, 0.010 mSv; maxillary occlusal, 0.007 mSv; intra-oral periapical radiograph, 0.005 mSv.
Conclusions: CT scans produce significantly more ionising radiation than conventional radiographs. This factor should be taken into account when considering a CT scan as an alternative to a survey with conventional radiographs. While CT scans offer many advantages over conventional radiography the high radiation dose to patients, and the cost of this procedure should be considered.
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Introduction

Computed tomography has been advocated for the management of a variety of conditions such as impacted teeth, root resorption,[1,2] cleft palates, site planning for implants,[3-5] facial fractures,[6,7] and deformities of the face and jaws.[8-12] During computed tomography all information about a structure is captured digitally[13,14] with the result that new images can be generated by the in-built software without the need to take a new scan. This digital information can be reformatted to provide images in different planes, or to show the surfaces of the facial skeleton. CT scans, therefore, offer advantages over conventional radiographs for the detailed study of bony and/or soft tissue lesions/deformities. In some conditions a single CT scan may be preferred over multiple conventional radiographs because, unlike a conventional radiograph, it can provide three-dimensional information.

With the increasing use of computed tomography in oral diagnosis and treatment planning concern has been expressed about the high levels of X-radiation patients are subjected to during a CT scan, and the associated risks. The terms used to describe the different doses of X-radiation are: the “absorbed dose”, which is measured in Grays (Gy), and is the energy dissipated in tissue per unit mass; the “organ dose” (Gy), which is the amount of energy absorbed by an organ per unit mass after allowing for skin absorption; and the “effective dose”, which is measured in sieverts (Sv), and is the organ dose multiplied by a risk weighting factor based on the relative sensitivity of an organ to developing a cancer. Since the discovery of X-rays in 1895 by Wilhelm Konrad Roentgen their biological side effects have been the subject of concern.[15] The unwanted side effects of radiation depend on the radiosensitivity of an individual tissue, which is a function of the mitotic activity in a tissue.[16] Alcox[17] reports that within the head and neck region, the red bone marrow of the mandible, the thyroid gland, and the lens of the eye are the most radiosensitive tissues. The somatic risks from X-radiation include leukaemia, thyroid cancer, bone cancer, oesophageal cancer, brain and nervous system cancer, salivary gland cancer, mental retardation, and cataract of the eye.[18]

Increased risk of leukaemia from diagnostic radiographs may be the most significant risk of conventional radiography.[19,20] The total risk for a full mouth periapical examination is estimated to be 2.5 fatal malignancies per 10^6 individuals. The effective dose of a full mouth examination is equivalent to 84 µSv, which is approximately one week of background radiation.[18] The likelihood of a fatal cancer or serious ill-health resulting from a single panoramic radiograph is estimated at one per 10^6 individuals.[21] Danforth and Torabinejad[22] calculated that the risk of getting leukaemia after between four and eight periapical radiographs (taken at 90 kVp) was 1 in 7.69 million, and for thyroid gland neoplasia the risk was 1 in 667,000 individuals.[23] It has been estimated that the total radiation (20 x 10^5 µGy) from 10,900 endodontic films would be necessary to produce cataract changes in the eye.[24] It has been suggested that, while conventional dental radiography is not without risk, the actual risk of a radiation-related disease is very small.[3,18,22]

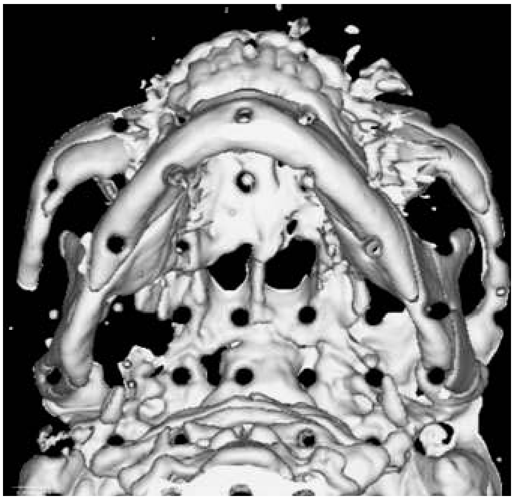
In assessing the radiation dose and risk following CT scans of the maxilla and mandible, Frederiksen *et al*.[25] reported that the radiation doses from maxillary and mandibular CT scans of contiguous 1 cm slices were 0.1 and 0.76 mSv respectively, compared to 0.026 mSv for an OPG.[26] The risk of morbidity from either a maxillary or a mandibular CT scan was calculated to be approximately 1 in 15,800 individuals. This was more than six times the risk of a full mouth series of periapical films, and more than 30 times the risk of a single panoramic radiograph. Ekestubbe *et al*.[3] assessed the organ dose from CT scans of the maxilla and mandible, and reported that the skin surface dose was particularly high (35–38 mGy). High doses were delivered also to the parotid gland (31 mGy), the submandibular salivary gland (27 mGy), and the eye lenses (5.5 mGy). The equivalent absorbed doses for conventional tomograms of the parotid gland (0.07–4.3 mGy), submandibular salivary gland (0.31–5.3 mGy) and eye lens (0.02–0.15 mGy) were much lower. The skin dose for conventional tomograms was not measured.

While these studies are informative, they do not provide an estimate of the radiation dose from a single CT scan of the facial structures that might be taken in preference to multiple conventional films, nor do they include a comparison with intra-oral plain films. The aims of the present study were to measure the radiation doses of maxillofacial CT scans, and to compare the radiation doses during these procedures with the radiation doses resulting from an OPG, a lateral cephalometric radiograph, an occlusal film, and a periapical film.

Materials and methods

An Alderson-Rando anthropomorphic phantom head (The Phantom Laboratory, New York, NY, USA), consisting of a human skull housed in material resembling the investing soft tissues, was used in the analysis (Figure 1). The head was cut into nine horizontal sections of equal thickness. Vertical holes, laid out in a grid pattern, passed through each section (Figure 2). Three lithium fluoride thermoluminescent dosimeters (TLD), measuring 3.5 mm x 3.5 mm x 0.9 mm, were placed in the vertical holes corresponding to: the eye lenses, the pituitary gland, the

◁ **Figure 1.** Anthropomorphic phantom head.



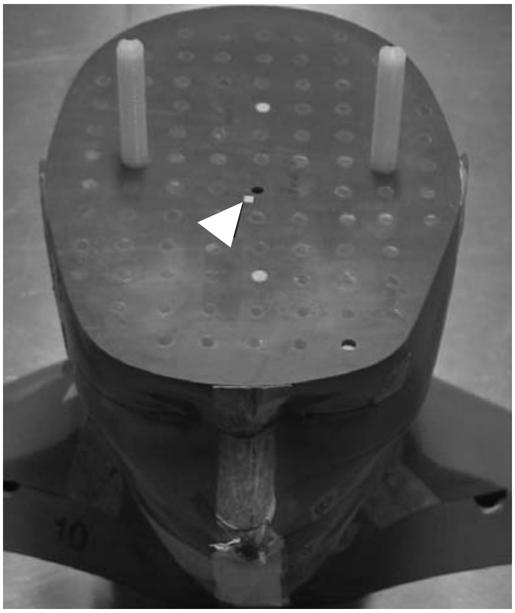


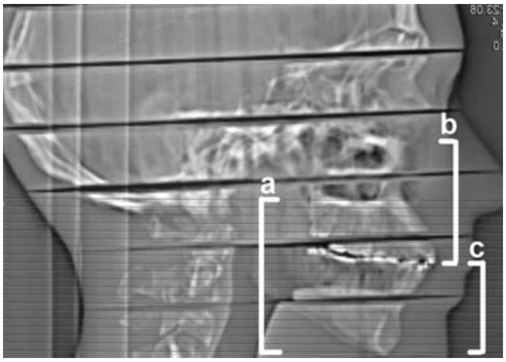
Figure 2.

(a) Submental CT view showing the grid pattern of vertical holes.

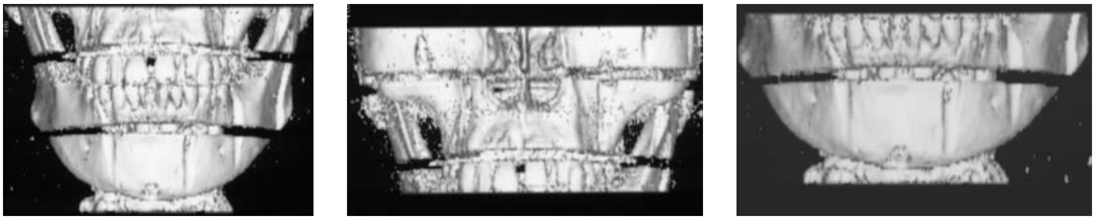
(b) The phantom head with sections 1 and 2 removed to show the vertical holes used to hold the TLDs. A TLD is adjacent to the centre hole.

parotid glands, the maxillary bone (anterior palate), both mandibular rami, the mandibular angles (at the sites of the third molars), the skin (the lips in the midsagittal plane), and the thyroid gland.[27,28] A total of 36 TLDs was used.

The same TLDs, used to measure the dose at each site, were used to calibrate the CT scans and measure the background radiation. Calibration of the TLDs, for both the CTs and the conventional films, was performed so the TLD dose reading could be given in Grays. On the day prior to exposure all TLDs were prepared by "annealing" them in a TLD oven (PTW, Freiburg, Germany) three times at 240°C for 10 minutes. They were read the day after exposure using a Toledo 654 Reader



◁ **Figure 3.** Initial scan: (a) Initial scan used to plan the MxMdCT scan, (b) MxCT scan, (c) MdCT scan.



(a) (b) (c)

Figure 4. CT surface scans used to show three-dimensional form. The vertical holes for the TLDs appear as grooves: (a) MxMdCT, (b) MxCT, (c) MdCT.

(Vinten Instruments, England). The mean of the three TLDs at each site has been used in all calculations. The background radiation dose received by the TLDs prior to exposure was measured by placing the TLDs in the phantom head overnight but not irradiating them. The background dose was then subtracted from the averaged readings taken during each scan. The CT scans were calibrated using a poly methyl methacrylate rod with 15 TLDs held in slots along the length of the rod, and read in a pencil chamber.[29,30] The conventional films were calibrated by exposing 15 TLDs in a 1800 cc ion chamber to a known absorbed dose, and the resulting radiation measured with a Radcal MDH 9010 dose meter (Radcal Corporation, Monrovia, California, USA). Effective doses were then calculated by applying weighting factors to the organ doses.[26,31,32] Comparisons of the effective doses to natural radiation levels were calculated using an approximate dose of 2 mSv per year.[27,33]

CT protocols

All CT scans were taken using a Siemens Somatom Plus 4 Volume Zoom (Siemens, Erlangen, Germany). To simulate the supine position adopted by patients having a CT scan the phantom head was placed on a table with the base of the head perpendicular to the floor, and the long axis of the head parallel to the table top. The same radiographer positioned the phantom head for each scan. An initial “scout” exposure was used to plan each CT scan (Figure 3). Three CT scans were taken: a maxillomandibular scan (MxMdCT) taken at the level of the lower border of the mandible to the level of the palatal plane, a CT of the maxilla only (MxCT) taken from the infra-orbital margins to the tips of the maxillary incisor teeth; and a CT scan of the mandible only (MdCT) taken from the incisal edges of the lower incisors to the lower border of the mandible (Figure 4). The parameters used for each CT are given in Table I. Each scan had a pitch of 1:1, that is, there was no spacing or overlap between the slices.

Conventional radiography

The exposure details for the conventional radiographs, which correspond to those used for an adult male, are given in Table I. The

Table I. Exposure details.

	View	Thickness (mm)	Collimation (mm)	Exposure time (secs)	Tube potential (kVp)	Current (mA)
CT scans	MxMdCT	1.25	1	21.25	120	150
	MxCT	1.25	1	9.47	120	150
	MdCT	1.25	1	12.64	120	150
Conventional	Ceph			0.5	80	12
	OPG			15	73	5
	MxO			0.5	60	7
	IOPA			0.2	70	7

Table II. Measured X-radiation.

	TLD Location	Film/scan						
		MxMdCT	MxCT	MdCT	Ceph	OPG	MxO	IOPA
Measured organ dose (mGy)	Eye lens	5.52	23.69	1.96	0.052	0.007	0.07	0.025
	Maxillary bone	38.18	22.27	23.48	0.039	0.095	0.228	0.116
	Parotid gland	28.85	20.95	4.35	0.106	0.277	0.008	0.008
	Mandible body	30.02	19.05	30.1	0.069	0.093	0.03	0.055
	Mandible ramus	33.88	19.44	24.02	0.088	0.364	0.018	0.015
	Brain	23.79	19.25	4.4	0.005	0.043	0	0.002
	Thyroid	2.97	2.69	2.35	0.026	0.009	0.007	0.011
	Skin	41.11	25.43	33.98	0.023	0.071	0.384	0.273
Effective dose (mSv)		2.11	1.4	1.32	0.005	0.01	0.007	0.005
Natural equivalent (time)		11 months	7.5 months	7 months	20 hours	40 hours	28 hours	20 hours

cephalometric radiograph (Ceph) and OPG were taken with a PM 2002CC Proline Cephalogram CM (Planmeca, Helsinki, Finland) with the phantom head placed in the normal position for each radiograph. The maxillary occlusal (MxO) and intra-oral periapical (IOPA) films were taken with a Siemens Heliodent 70 Dentotime X-ray unit (Siemens, Erlangen, Germany). For the MxO, a standard occlusal film was inserted between the sixth and seventh sections of the phantom head to simulate, as closely as possible, the clinical situation. For this view the anode was placed in the midline, and angled downwards 70 degrees to the horizontal. The IOPA was taken with a periapical film positioned in the maxillary canine region between the sixth and seventh sections of the phantom head. Because of the design of the phantom head this film had to be placed horizontally.

Results

The absorbed doses of the CT scans and conventional radiographs are given in Table II. Overall, much greater radiation was measured during the CT scans than during conventional radiography. During a scan, sites remote from the area of interest received more radiation than the plain films. The radiation dose to the TLDs representing the eye lenses was highest in the MxCT scan (23.69 mGy) because the beam was close to the eye, and lowest in the OPG (0.007 mGy). The highest dose to the bony structures (38.18 mGy) was recorded in the maxillary bone during the MxMdCT scan, and the lowest dose to the bony structures was measured in the mandibular ramus (0.015 mGy) when the IOPA was taken. The doses received by the bones during scanning ranged from 19.05 to 38.18 mGy. The highest dose to the TLDs representing the skin occurred during the MxMdCT scan (41.11 mGy), and lowest "skin" dose (0.0023 mGy) occurred when taking the cephalometric radiograph. During the MxMdCT scan the TLDs representing the parotid gland received a lower dose (28.85 mGy) than either the mandible or the maxilla. The parotid site received equally low doses (0.008 mGy) during the MxO and the IOPA. The thyroid site received the highest dose (2.97 mGy) during the MxMdCT scan, and the lowest dose during the MxO film (0.007 mGy). The TLDs representing the pituitary gland received their highest dose during the MxMdCT scan (23.79 mGy), and their lowest dose (0 mGy) during the MxO. The TLDs representing the skin received a high reading of 41.11 mGy from the MxMDCT scan, compared to a low 0.023 mGy from the cephalometric radiograph.

The effective dose and the equivalent background radiation from natural sources are given in Table II. The measured organ doses were markedly higher from the CT scans than the measured doses from the plain films. The IOPA and Ceph films had the lowest effective dose at 0.005 mSv, followed by the MxO (0.007 mSv), OPG (0.010 mSv), the MdCT scan (1.32 mSv), and the MxCT scan (1.40 mSv). The highest effective dose was the MxMdCT scan (2.11 mSv).

Discussion

The data captured in a computed tomogram can be manipulated using specialised software to view an area(s) of anatomical interest without the need to take an additional scan. While CT scans offer several advantages they also have some important disadvantages compared to conventional radiographs, namely, the high radiation dose to a patient and the higher cost. Although multiple plain films may not yield the same information as a single CT scan they do, however, result in less radiation to a patient, are relatively inexpensive, and are simple to take. The present study aimed to compare the radiation doses from three different maxillofacial CT scans with the radiation doses from the plain radiographs used in orthodontics.

An anthropomorphic phantom head was used in this study because the X-radiation could be measured at the sites comparable to important structures, such as the eye. In contrast, use of a cadaver[34] would have required ethical approval, transport to the CT machine, and dissection to accurately place the TLDs. Surface doses can be measured on patients,[4] but subjecting a patient to multiple radiographs with high radiation doses merely for comparative purposes would not have been allowed.

In agreement with other studies, the radiation doses from the CT scans were much higher than those obtained during conventional radiography.[3-5,35] Using a similar protocol to that used in the present study Ekestubbe and co-workers[3] measured the absorbed dose from CT scans of the maxilla, the body of the mandible, and during a frontal scan of the mandible. Although their maxillary scans did not extend to the infra-orbital margins, and their exposure times were slightly shorter than the ones we employed, their findings are similar to the present study. At sites representing radiosensitive organs they reported the following doses: skin (35–38 mGy), eye lens (0.6–5.5 mGy), pituitary gland (1.0–2.6 mGy), and thyroid gland (0.6–4.0 mGy). The lower absorbed dose by the lens of the eye during their MxCT scan can be attributed to the smaller area scanned. The majority of Lecomber *et al.*[5] findings from MdCT scans also agree with the present study. Small disagreements in the doses obtained for the sites representing the skin, bone marrow, and bone surface may be due to the location of the TLDs, which are not described.

Non-patient factors may affect the absorbed dose. Radiation output may vary from one CT machine to another, and different radiographers may use different scanning protocols.[36,37] In one study,[37] a total of 14 different CT machines was assessed using a Perspex phantom and an anthropomorphic phantom head. Variations were found between machines from different manufacturers, and between similar machines from the same manufacturer. The latter may be due also to differences in positioning the phantom heads for each exposure. Other factors that can contribute to variations in radiation dose include the scanner geometry, and the beam quality and geometry.[38]

The slice thickness affects the quality of a CT image. In the present investigation the slice thickness was set at 1.25 mm with a 1 mm collimation and a pitch of 1:1. There is some evidence to suggest that although scans with thicker slices contain less detail they still give adequate diagnostic information. Ericson and Kurol[39] used 2 mm contiguous slices to identify root resorption on lateral incisors, and McGurk *et al*.[6] used 3 mm contiguous slices to assess orbital floor blowouts and traumatic enophthalmos. Others[7] have reported that 5 mm coronal CT scans are adequate for the diagnosis of midface trauma. Preda[1] compared pitches of 2:1 and 1:1 to locate impacted canines, and reported that a pitch of 2:1 was adequate for accurate diagnosis.

As a rule organs situated in or close to the primary beam experienced the highest radiation doses, and this applied to both forms of imaging: CT and conventional radiography. Thus, the highest dose to the eye was recorded with the MxCT scan, and the lowest dose was recorded with the MdCT scan. The MxMdCT scan resulted in high doses to the other organ sites, particularly the maxilla and mandible. The high absorbed dose by the bones of the face may increase the risk of radiation-induced leukaemia.[19] Of the conventional films the cephalometric radiograph gave the highest doses to the eye and the thyroid gland. Although this dose was low compared to that found in other sites, and particularly during CT scanning, it would be prudent to protect the sensitive lenses of the eyes with some form of shield.

Theoretically a CT scan could replace plain films for diagnostic purposes, but radiation hygiene alone prohibits this. For example, the effective dose due to a MxMdCT scan is 2.11 mSv whereas the effective dose due to an OPG is only 0.010 mSv, and 0.005 mSv during a cephalometric radiograph. Furthermore, if an initial radiographic survey (Ceph and/or OPG) indicated further radiographic investigation was necessary then an IOPA would provide an effective dose of 0.005 mSv compared to 1.40 mSv by a MxCT scan. With such great differences between the effective doses a low-dose conventional film may be easy to justify, but a high-dose CT scan may be impossible to justify unless it can provide sufficient clinical advantage to justify the increase in effective radiation. One must also consider that a patient may require radiographic investigations in other branches of health care. Given the relative sensitivity of bone marrow and eye lenses to X-radiation,[19,20] particularly in young patients, the choice of adjunctive radiograph(s) should be considered carefully. Untoward health changes from radiation exposure may take several years to manifest, and radiation received by a child has greater clinical significance than the same dose received by an adult.[40] Reducing the radiation dose to a patient by reducing parameters such as the slice thickness, the tube potential, the current and exposure time,[1,6,7,39] require further investigation. New developments in the technology promise to provide similar diagnostic information to that found on a CT scan, but with doses comparable to an OPG.[41-43]

While computed tomography is capable of providing accurate images with a high diagnostic yield and can be used instead of plain films, the effects of the high radiation on patient morbidity and mortality are contentious issues.[44] The extent to which the management of a problem is influenced by the information found only on a CT scan varies from case to case,[44,45] and set against this are the disadvantages of the high effective radiation dose to radiosensitive organs, and the additional cost of the procedure.

Conclusions

1. Computed tomography results in a significant increase in ionising radiation compared to conventional radiography. Because of this a CT scan as an adjunct to an initial plain film survey may not be justified.
2. Decisions whether or not to take a CT scan should include consideration of the advantages over conventional radiography, the radiation dose, the cost, and whether a CT examination will change the treatment approach significantly.

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