Measurement of lifetime dental radiographic radiation exposure to the cranial meninges

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This is to certify that I have examined this copy of a doctoral dissertation by

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Abstract

Measurement of lifetime dental radiographic radiation exposure to the cranial meninges

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The overall goal of this investigation was to measure the ionizing radiation dose to the cranial meninges from a lifetime of self-reported dental radiography. The first aim was to estimate the radiation-absorbed dose to the cranial meninges from 1920 to 1993 for common dental intraoral radiographic techniques. Data for these estimations were derived from statistical models created from the published literature. Over these 73 years, the estimated dose to the pituitary gland showed almost 30 fold reductions from 9,000 to 342 microGray (μ Gy) for a full mouth survey, and proportionally similar reductions for 4 bitewings and single molar periapical film. The relatively high doses to the clivus region of the brain for multiple full mouth radiographs during the 1920's to 1960's was less but still similar in magnitude to radiation treatment for tinea capitus, which has been shown to be tumorigenic. The second aim was to determine the number of x-rays exposed on patients, using on-site abstracted records, claims data along with a survey of dentists self report. Results showed that, although the discrepancies between routine exposed and recorded x-rays are generally small (<10%), some procedures, such as root canal therapy and orthodontic treatment, expose substantially more x-rays on patients (2 to 3 times) than are recorded, stored or billed. The third aim was to determine

the number of dentists visited over a subject's lifetime, not just those who were recalled. Using capture-recapture methods, with records retrieved from offices and subject recall, showed that 79% of all dentists visited were recalled, yielding a lifetime total of 6.5 dentists visited, on average. The fourth aim was to compare the recall of lifetime dental x-rays by the subjects with dental records, measure the accuracy and precision, and search for differential bias between cases and controls. Dental records available before the reference date (n=298) were gathered for a subset of 74 of 200 cases and 84 of 400 controls. Compared to records, cases and controls over-reported bitewing (148%, 138%) and full mouth (144%, 129%) visits, and under-reported panoramic (59%, 80%) and cephalometric (17%, 50%) visits, respectively.

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PREFACE

The overall goal of this investigation was to determine as accurately and precisely as possible the actual absorbed dose of ionizing radiation to the cranial meninges from self-reported dental radiography for the subjects in the meningioma risk factor study. This task was accomplished through a series of steps at different levels of observation. First, the dose to the meninges from dental intraoral radiographs by year was determined. The exposure at the cellular level of the meninges, the target organ, was correlated with a single dental x-ray or dental x-ray procedure on the macroscopic level. Second, lifetime dental radiographic utilization was estimated by using multiple, overlapping sources of dental records. The gold standard of lifetime dental x-rays was estimated by comparing recorded x-rays with those stored in the chart and billed. Thus, the single x-ray or single x-ray procedure that was exposed on the patient was correlated with the recorded, stored or billed evidence of the exposure for episodes of dental care. Third, capture-recapture methods were used to estimate the total dental providers visited in a subject's lifetime. This related the recorded dental x-ray visits for a single provider to a lifetime of dental x-ray visits from usually multiple providers. Fourth, recorded dental x-ray visits over a lifetime could be related to the ionizing radiation dose to the meninges. Finally, dental records were retrieved for a subset of the subjects, and these records were compared with the self-report of the subjects. The accuracy and precision of recall was determined, and differential bias between the cases of meningioma and controls was assessed of various dental x-ray procedures over different time periods.

This dissertation is organized into multiple chapters that have been written for separate publication in scientific journals. The intended audience for the separate papers differs. Chapter two is written for a dental specialist /oral and maxillofacial radiologist audience. Chapter three is written for a dental specialist/oral epidemiologist reader. Chapters one, four, five and six are intended for a general epidemiological audience.

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Danilee Baldwin, DDS, assisted in the survey of dental practice and abstracted hundreds of dental charts, both in office and of collected records. Over three hundred dentists in the United States cooperated with detailed requests for dental treatment records, and over 50 allowed myself and other personnel to abstract the dental records on-site in their offices. Several hundred dentists took part in the *Survey of X-ray Practice in Dentistry* without any monetary incentives.

Michael Odlaug, MPH, Head, X-ray control, Division of Radiation Protection, Department of Health, State of Washington, allowed use of the state database of dental x-ray inspections over the past 9 years, along with older inspection records from the 1960's.

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Linda LeResche, ScD and Christine Ritchie, MD, MSPH, served as my ad hoc PhD advisors in the final two years of preparation, and without their encouragement and guidance, I may never have finished writing this dissertation.

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Lars Hollender, DDS, Dr. Odont. helped me throughout the study with his many hints from his 47 years of experience in dental radiography. It seems fitting that he began his academic career with a pioneering dental x-ray dose estimation study, and is now closing it with another.

Will Longstreth MD, MPH thought of the idea of the main study, wrote the grant, got it funded and made sure I completed this project. I especially appreciated his leadership and guidance at the end of the study.

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Finally, I thank my wife, Heather, children, Thomas and Lina, mother, Hartrice, and entire immediate family for their unending love and support during the duration of this study.

DEDICATION

Issac Daniels 1958 - 1978

On a warm summer evening in early September, 1978, around 6:25 pm, Isaac Daniels offered to take my place and perform the unwanted task of cleaning a large industrial pancake mix blender at Continental Mills, Inc, Kent, Washington, where we both worked. A few minutes later, while cleaning the blender, Issac became unconscious from a lack of oxygen in this closed space, which had been displaced by a new nitrogen cooling system, and he was pronounced dead by paramedics about 15 minutes later. I almost certainly would have suffered the same fate if Isaac had not unselfishly volunteered to do this work for me. For this, I am eternally grateful and dedicate this doctoral dissertation in memory of him.

Chapter 1: Background and Significance

Ionizing radiation has been shown to cause benign brain tumors such as meningiomas in two separate cohorts – atomic bomb survivors (1) and in children who were treated with radiation for ringworm of the scalp in the 1940's to 1950's (2). Both of these studies show a dose-response relationship; in the first, between the reconstructed radiation dose from the bomb and the incidence of meningiomas (Figure 1.1), and in the second, between the reconstructed dose to the brain from the scalp treatment and relative risk of brain tumors (Figure 1.2). Both studies have also shown a long induction period of 20 to 40 years before the tumors became clinically evident. However, at doses lower than 0.10 Gray (Gy), the relationship between radiation dose and risk for tumors is less clear. Many scenarios may exist, four of which are: 1) a linear, proportionally increasing risk with increasing dose; 2) a sub-linear increased risk, 3) a supra-linear increase in risk; or 4) even the possibility of protection from risk at lower doses ("hormesis") (Figure 1.3). This question of whether very low dose diagnostic radiation can be harmful is still a concern today, especially with the increasing use of medical radiography, including procedures such as computed tomography (CT) (3). For example, CT scans of the head can yield brain absorbed doses in the range of 30 to 50 milliGray(mGy) in the 1990's (4), and multiple scans over a lifetime are not uncommon. If these lower level radiation doses were found to be harmful, such findings would have broad implications in public health, from determining the risk of low-level radiation from diagnostic radiography or frequent airplane travel, to guidelines for cleanup of nuclear power facilities.

Besides CT, dental radiography is one source of ionizing radiation that may be in this very low (less than 50 mGy) but potentially harmful range. Although the individual doses for each film is generally lower, the volume of services is high, and dental radiography was previously the most common diagnostic radiographic procedures performed in US from ~1930 to ~1980 (5). Multiple studies conducted over the last 20 years have variably shown an increased risk of meningiomas from dental x-rays (6;7), or not (8). Epidemiological studies of other neoplasms have also shown associations with dental radiographs (9-11))(9;12-17), although most of the associations are less than 2.0 with 95% confidence intervals that include unity, while still other studies have not shown positive relationships(18).

One reason for these discrepancies is that each study has had differing exposure measures of dental x-rays– from crude measures, such as ever/never been exposed to dental x-rays (9;11;19), to more complex measures such as the number of full mouth x-rays (FMX) before 1945 (8) (see table 1.1). The absorbed dose of radiation from a dental x-ray depends upon the number, year, type of film, and machine-film technical factors, as will be presented in chapter 2, and studies that do not provide this information are substantially limited. Only three previous studies asked subjects to recall the number, year, and type of dental x-rays taken in their lifetime (6;8;12), and this work was done with supplementary interviews and detailed lists of probes to enhance recall. In addition, most studies asked subjects to recall the total number of dental x-rays taken in their entire lifetime with one to two questions, rather than splitting their life of dental care into discrete periods of treatment by multiple, separate dentists. The effect of these limitations is to generally decrease the number of x-rays recalled by the subject, as shown by the few lifetime x-ray visits reported in most studies, compared to known rates of dental x-ray utilization in the US population over the past 50 years (20;21). On the other hand, the potential for subjects to report more x-rays than actually occurred is also possible. Methods to enhance long-term recall (22), but not increase over-reporting, are needed if only subject self-report is to be used. Finally, the actual radiation dose to the target organ from dental radiography would be a preferred exposure measure, since it is the closest one can get to the active dose, and the active dose is most likely to demonstrate an association between the agent and disease (23). However, only one previous study has reported such dental doses (12) while no previous studies of brain tumors have done so.

An ideal exposure measure would be to implant dosimeters capable of differentiating dental radiation from other sources into the meninges of a large cohort of humans at birth, and then measure the dental radiation dose rates per year, the highest dose, the average dose and the cumulative dose at these various sites around the skull over time, and see if the number of people with higher doses were more like to develop meningiomas than those people with lower doses. Since this is presently unfeasible (no such sensors are available) and unethical (harm likely to patient with no benefit), an alternative would be to gather the lifetime dental records for people with meningiomas and those without, so that the number, type and year of the dental x-rays films exposed on a person could be summed up. Next, radiation survey records for each dental x-ray unit, or, alternatively, the type of x-ray film and x-ray machine used, could be retrieved so that the radiation exposure to the surface of the skin of the face could be calculated. Then, the dose to the brain and meninges could be estimated using studies that have utilized implanted dosimeters inside phantoms, or dose equivalent replicas of human heads. This should allow a close approximation of the dose rate and cumulative dose to specific area's of the cranial meninges from a lifetime of dental radiography.

However, there are obstacles to this seemingly straightforward plan. Since there is no national dental care system in the United States, and private dentists provide almost all care, there is no master record of all dental care performed. The total number of dentists visited by a person in a lifetime, and care provided, is not easily determined, and depends upon the long-term recall of the treated person. In addition, dental records are only legally required in Washington state to be retained for 5 years past the year when the patient was last seen , and many are lost or disposed of a few years later as dentists make space for newer records, move or sell their practices, retire, or die. Furthermore, it is not known what proportion of dental x-rays exposed on patients is actually listed in the dental chart, since some x-rays are included in the fee for related procedures, and are not routinely recorded. And, the exact dental x-ray machine used, although recorded in many states since the late 1960's, is not easily found today since most of these records have been destroyed, and no surveys were done before this time. Dosimeter studies using human skulls have only been completed for some years, machines and techniques. The highly complex anatomy of the anterior skull, with air-filled sinus cavities, thick bony structures, and varying layers of soft-tissue makes the use of standard radiation dose reference tables for estimating dose to bone marrow difficult, since these references assume simple and consistent layers of tissue. Thus, although it is theoretically possible to measure the dose to the brain and meninges from a lifetime of dental radiography for any given person, in reality, it is challenging, and may not be feasible, so that novel methods must be devised to measure and count up the lifetime radiation dose to the brain. Lastly, if the self-report of lifetime dental radiographs is accepted as the true measure of radiation exposure, concerns exist that people with recent, surgically removed brain tumors, compared to controls without such an adverse life event, may not accurately recall these events. At least three scenarios are possible: 1) because of the commonly perceived relationship between cancer and radiation, case subjects will overestimate the number of radiographs taken; 2) since cases have had brain trauma from the tumor and surgery, or because some cases have died or were incapacitated, and proxy respondents were used, they may say they don't know or will underestimate the number of radiographs; or 3) cases and controls recall dental radiographs in the same fashion. A careful study for differential bias between cases and controls by using an external gold standard such as dental records is the only way to find the answer to this question. This dissertation describes the methods used to overcome these obstacles and measure up to a lifetime of ionizing radiation dose to the cranial meninges for subjects with meningiomas and population-based control subjects.

Figure 1.4 illustrates the overall plan of this dissertation to accomplish the goals of determining the radiation dose to specific areas of the cranial meninges, and then comparing subject recall to records. From top to bottom, chapter 2 describes how the dose to the cranial meninges was estimated, given a specific type of dental intraoral radiographic procedure. Chapter 3 estimates the actual number of dental films exposed on a subject, given the number indicated on records, stored in the chart, or billed to insurance. Chapter 4 describes how lifetime dental providers were estimated, so that a lifetime of dental radiographic utilization can be determined. Chapter 5 measures how accurate and precise the recall of dental radiographs was by subjects, compared to this enhanced reference standard and describes if differential bias between cases and controls occurred different time periods of exposure. Finally, these steps allow the estimation of the ionizing radiation dose up to a lifetime to specific parts of the cranial meninges, given a history of self-reported dental radiography.

The aim of chapter two was to estimate the mean radiation-absorbed dose to the brain and cranial meninges for the US population since 1920 for the following dental radiographic techniques: single periapical, 4 bitewings, and full mouth survey. The aim of chapter three was to estimate the number and type of dental radiographs exposed on a person for common dental radiographic procedures and procedures that are associated with radiographs, and also the fraction that recorded, stored and billed data provide of this total exposure. The aim of chapter 4 was to use capture-recapture methods to find the number of total lifetime dentists visited by subjects in a case-control study of benign brain tumors. The aim of chapter five was to) develop methods to facilitate recall of lifetime dental x-ray visits; 2) determine the agreement of recall and records of dental x-ray visits over a lifetime by subjects; and 3) assess if differential bias between cases and controls occurred.

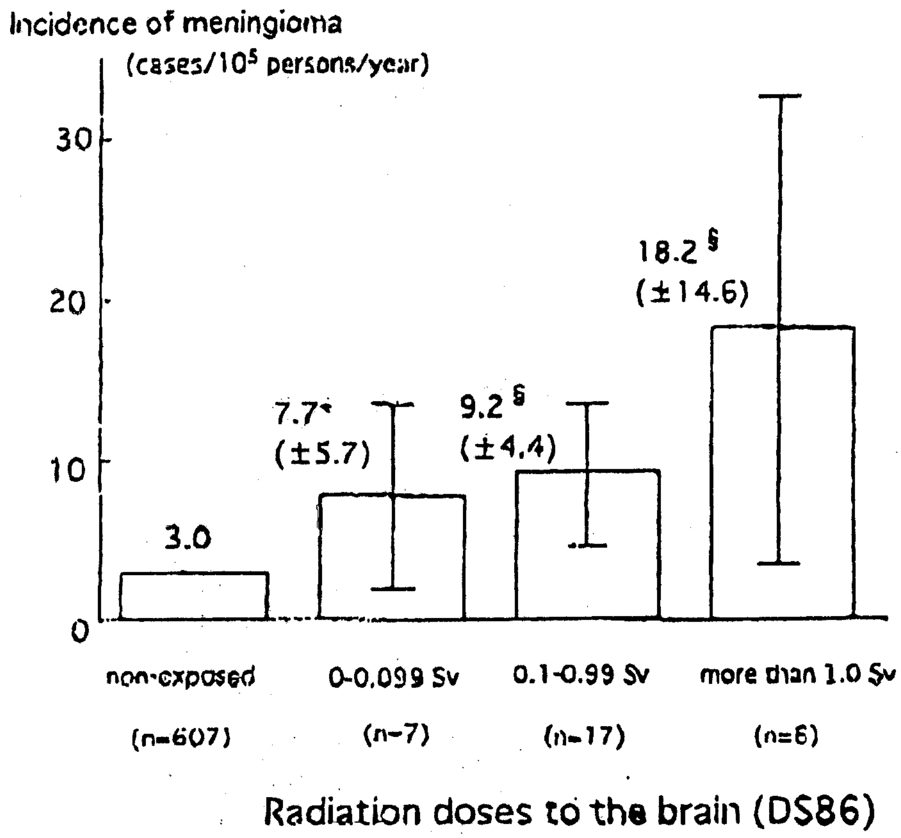


Figure 1.1 – Incidence of meningioma versus radiation absorbed dose to the brain for atomic bomb survivors.

A dose-response relationship is shown between the dose to the brain from an atomic bomb and the incidence of meningioma, although the total number of subjects in the exposed categories is small. Reprinted from Shintani et al, 1999.

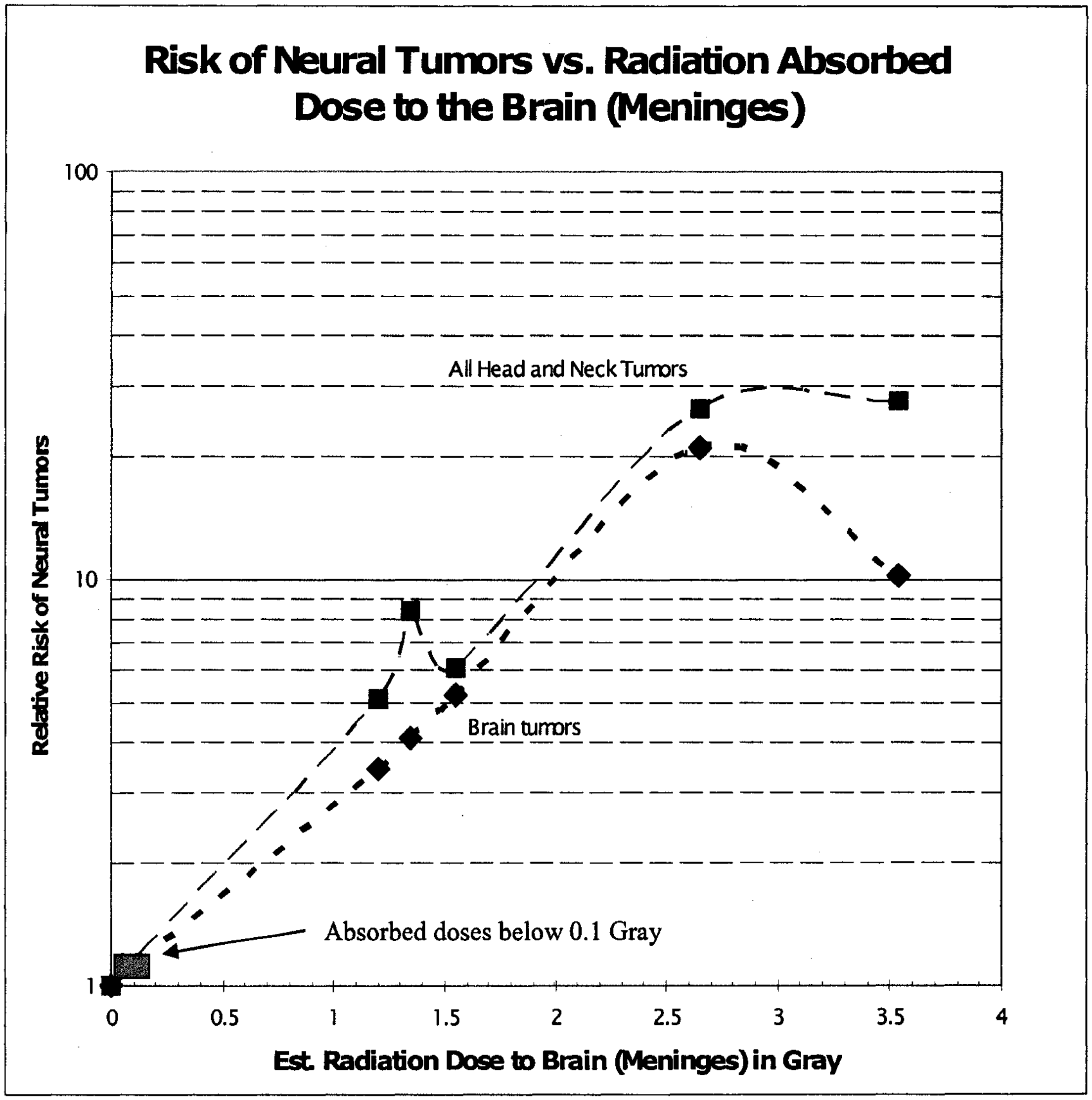


Figure 1.2. Relative risk of neural tumors versus ionizing radiation absorbed dose to the brain.

This figure shows a dose response relationship between the dose to the brain and meninges from tinea capitus treatment, and the subsequent risk of developing a head and neck or brain neoplasm. After 2.5 gray of absorbed dose, cell killing is one explanation of why the risk decreases. The figure is constructed from data given in Ron E. et al, 1988. The small box in the lower left corner indicates a dose of 0.1 Gy and below, where there is uncertainty of tumor risk and this section is illustrated in the next figure.

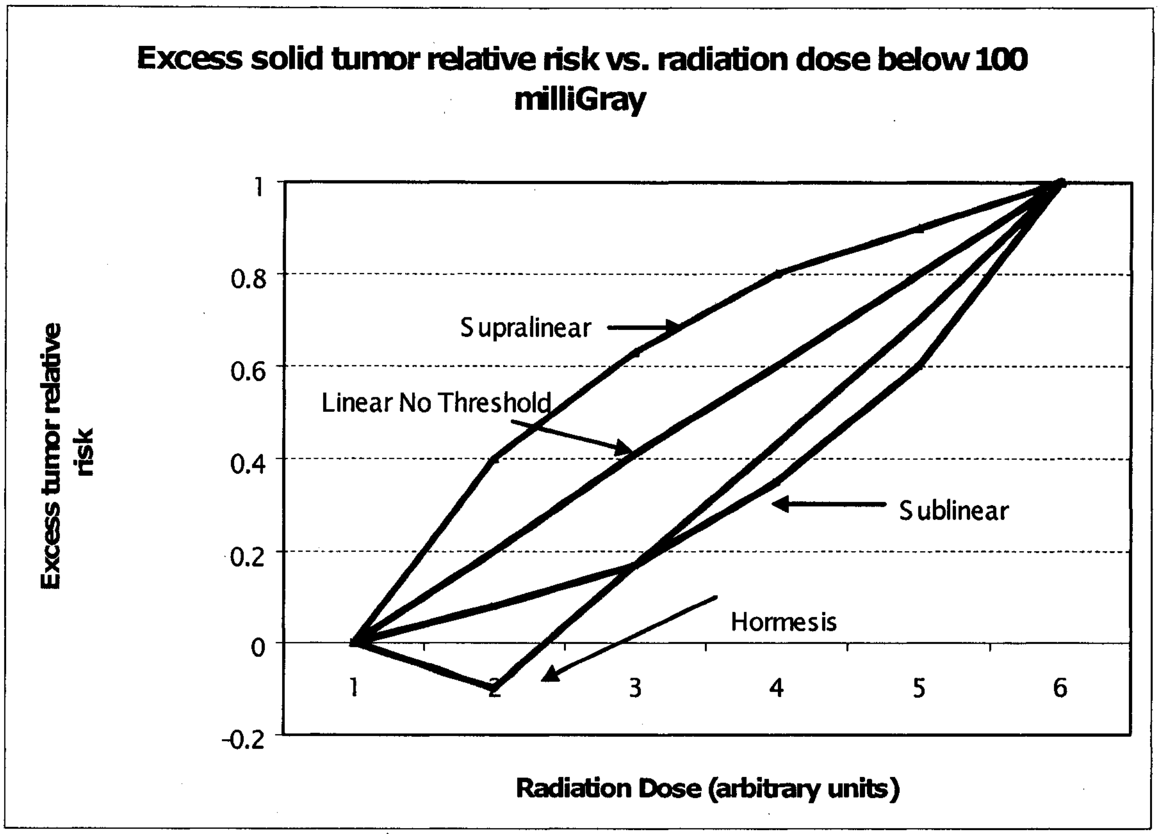


Figure 1.3. Excess solid tumor relative risk vs. ionizing radiation dose below 100 milliGray.

This figure shows the theoretical relationships between low-level ionizing radiation dose and the excess relative risk (equal to relative risk minus one) for solid tumors such as meningioma. Linear, no threshold relationships are presently the most accepted theory, although controversy exists. Sublinear (linear-quadratic) or supralinear relationships are hypothesized. Some investigators ascribe to the idea of 'hormesis', or decreased risk for tumors at very low doses. Threshold models show no risk at low doses and, after a threshold is reached, show usually linear increases in risk. .

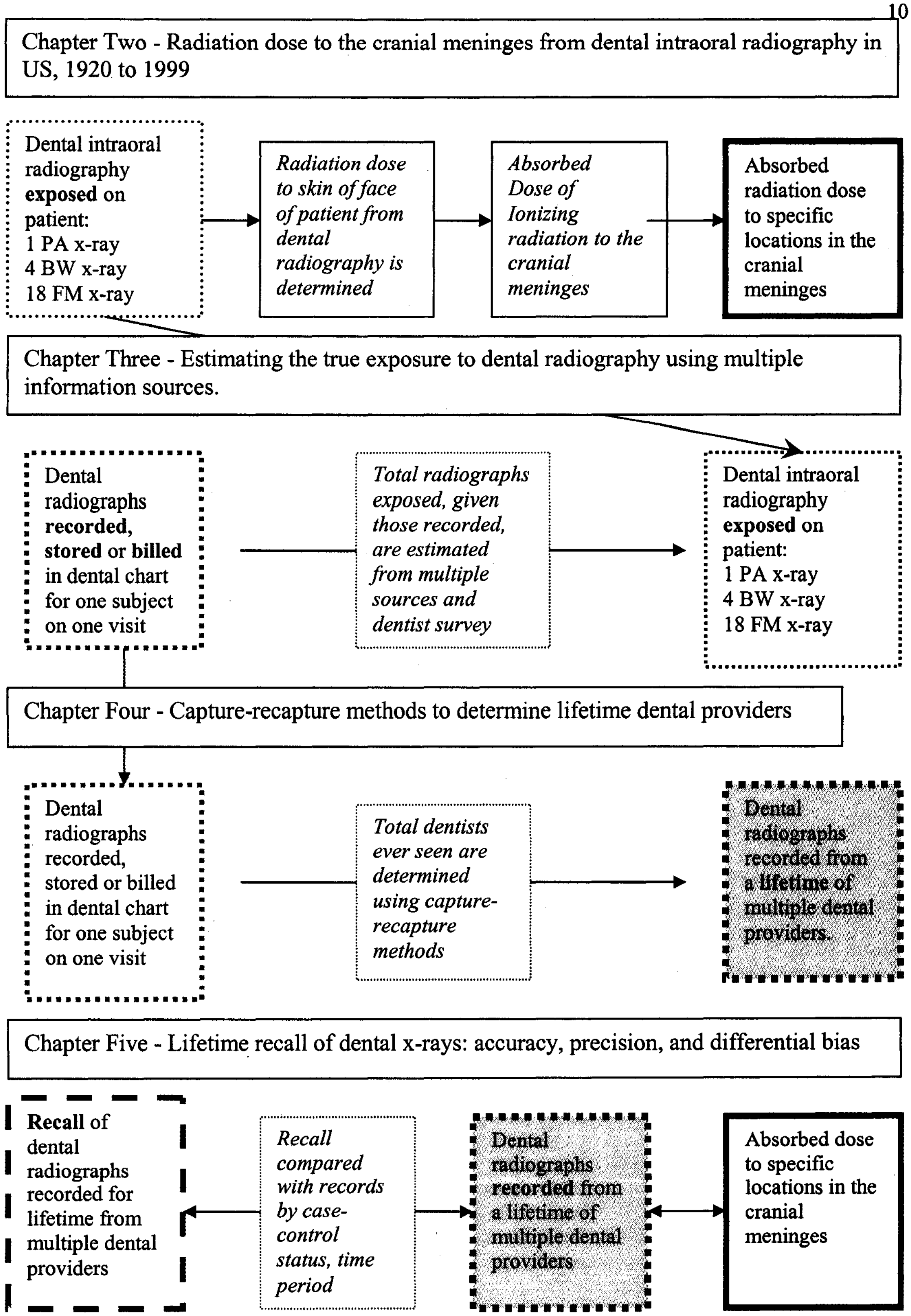


Figure 1.4 – Overall exposure measurement scheme. PA =periapical, BW = bitewing, and FM = full mouth, capture-recapture is a method to determine the total population given two overlapping lists of membership that borrows its name from studies counting wildlife.

Table 1.1 Prior studies of the risk of tumors from dental radiography.

First Author	Pub. Year	No. cases	No. controls	Any dental x-ray Exposure measures	Overall Odds Ratio	Percent controls ever exposed to any dental x-rays?	Asked subject to recall life-time of dental x-rays in only 1-2 questions	Year of dental x-ray noted?	Type of dental x-ray noted?	Number of dental x-rays noted?	Output of dental x-ray noted?	Calculated radiation dose to organ?
Meningioma												
Present	2004	200	400	Number of bitewing dental visits by each dentist seen	1.4	98%	**no**	yes	yes	yes	partly	yes
				Cum. dose to the meninges from 4 types dental x-rays								
Preston-Martin	1980	101	101	Ever exposed to FMX?	1.2	ns	**no**	yes	yes	yes	no	no
				Was FMX taken before or after 1945?								
Preston-Martin	1983	105	105	Ever exposed to FMX?	0.6	ns	**no**	yes	yes	yes	no	no
				Was FMX taken before or after 1945?								
Preston-Martin [1]	1989	70	70	Ever exposed to dental x-rays?	1.5	90%	yes	partly	partly	partly	no	no
				Number of any dental x-rays after age 25?								
Rodvall [1]	1998	99	343	Dental x-ray once a year or more since age 25?	2.1	ns	yes	partly	no	partly	no	no
				X-rayed less than every 5th year?								
Schlehofer [1]	1992	58	118	Ever exposed to dental x-rays?	0.6	72%	yes	no	yes	partly	no	no
				Ever exposed to panoramic x-rays?								
Ryan	1992	60	417	Ever exposed to dental x-rays?	1.4	62%	yes	no	?	?	no	no
				How old when you first had dental x-rays?								
Salivary Gland Tumors												
Horn-Ross	1997	141	191	Ever exposed to FMX?	1.6	ns	yes	some	yes	yes	no	no
				Ever exposed to panoramic x-rays?								
Preston-Martin	1988	408	408	Year and type of dental radiograph by each dentist?	1.5	ns	**no**	yes	yes	yes	attempted	yes
				Dose to parotid gland from dental x-rays								

Table 1.1 (cont.).

Thyroid gland												
Hallquist	1994	171	325	[Number and year of any dental x-ray examinations] [exposed to dental x-ray examination?]	1.3	ns	yes	**yes**			no	ns
Hallquist	2001	180	360	Number of dental x-rays from dental record	1.3	ns	yes	**yes?**	ns	**yes**	no	**attempt**
Glioma												
Preston-Martin [1]	1989	202	202	Number of any dental x-rays after age 25 Asked dentist not to take x-rays?	1.4	90%	yes	no	no	partly	no	no
Ryan [1]	1992	110	417	Ever exposed to dental x-rays? How old when you first had dental x-rays?	0.42	62%	yes	no	?	?	no	no
Any brain tumor												
Burch	1987	215	215	Ever exposed to dental x-rays?	1.25	ns	yes	no	no	no	no	no
Neuberger	1991	7	25	Ever exposed to dental x-rays?	10.7	40%	yes	no	no	no	no	no
Leukemia												
Gibson	1972	1414	1370	Has this child ever been x-rayed? Number of dental x-ray films to the teeth (records)	~1.2	ns	yes	**yes**	**yes**	**yes**	**partly**	no
Laryngeal Cancer												
Hinds	1979	47	47	Ever had dental visit that included dental x-rays? How many times did a visit to a dentist involve dental [association only among heavy smokers]	~5.0	ns	yes	no	no	**yes**	no	no

Legend 1- denotes authors all involved with an international collaborative study on brain tumors

ns = not stated

FMX - full mouth x-ray survey

[ ] indicate exposure measure gleaned from text, but not explicitly stated

Chapter 2: Ionizing radiation absorbed dose to the cranial meninges of the US population from dental intraoral radiography, 1920 to 1993.

Objectives: Important questions still remain of the risk of ionizing radiation from dental radiography. Although approximately one hundred studies of doses to human organs from various dental radiographic techniques have been published, no single study has summarized these studies' data in one paper, and shown the doses as trends over time. The aim of this study was to estimate the mean radiation-absorbed dose to the brain and cranial meninges for the US population since 1920 for the following dental radiographic techniques: single periapical, 4 bitewings, and full mouth survey. **Methods:** The data for these estimations were derived from statistical models of the published literature for: 1) US population-representative estimates of the entrance skin exposure from a periapical molar radiograph; 2) radiation penetration to the pituitary meninges from intraoral radiographs; 3) calculation of the meningeal pituitary dose by multiplying the values from #1 and #2; 4) calculation of the dose to different anatomic regions of the brain and meninges; and 5) estimation of population-representative dose to the meninges from 1 periapical, 4 bitewing and full mouth survey by direct measurement of radiation doses to the pituitary gland and temporal lobe regions of the brain with a tissue-equivalent skull. **Results**: Over this 73 year time period, the estimated dose to the pituitary gland showed an almost 30 fold reduction from 337 to 12 microGray (μ Gy) for a single periapical film, and similar reductions for 4 bitewings (1346 to 51μ Gy), and full mouth survey (9,000 to 342 μ Gy). The disparity in dose from one dental facility to another for most techniques was large, with upper to lower dose ranges differing by up to 100 times. The foramen magnum and clivus region of the brain, which is posterior and inferior to the pituitary gland, showed the highest doses. **Conclusions:** Large reductions in the radiation dose to the brain from dental intraoral radiography have occurred over the last 73 years. The relatively high doses of radiation to the clivus region from multiple full mouth radiography in the 1920's to 1960's were similar in magnitude to radiation treatment for tinea capitus, which has been shown to be tumorigenic. Whether repeated doses of dental diagnostic radiation at these levels over decades can initiate or promote brain neoplasms remains an unsettled question.

Introduction

Dental radiography has evolved rapidly over the last century, with the introduction of new machines, smaller beam sizes, increased filtration, advanced techniques, faster film speeds and large increases in utilization (24). Concerns remain about the possible adverse effects of dental radiography on humans for several reasons: first, these procedures remain the only common type of diagnostic radiography that is performed without intensifying screens, requiring concomitantly higher doses; second, the target to film distances are short; and third, the emitted rays are in close proximity to sensitive organs in the head and neck region. In addition, these examinations are among the most common diagnostic radiographic procedures performed today, with over 118 million procedures and 515 million dental films taken in the US in 1984 (25). Previous studies have shown an increased risk for salivary gland (12), thyroid (14;15)and brain tumors(6;8) from prior exposure to dental radiographs although most studies have relied only upon the self report of lifetime dental radiographs to assess exposure, and doses to target organs were only calculated for the salivary gland study.

The absorbed doses of ionizing radiation to critical organs from dental radiography have been estimated by the use of tissue equivalent human skulls (commonly called 'phantoms'), by examiners exposing dosimetry film in offices, through the placement of dosimeters on human subjects, and with Monte Carlo computer simulations in now over 90 studies during the past 50 years. Several previous authors have summarized the results of some of these studies in general (24;26) or for their effects on specific organs, such as the parotid glands (12). Unfortunately, the type of radiographic equipment and techniques in use at any given time has varied, and it is difficult to know if the methods used with the reported phantoms or small samples of subjects resulted in doses similar to those experienced by the populace at that time. These dental dose estimation studies typically have used the newest equipment and fastest film speeds and techniques, although dentists in practice are generally using older equipment and techniques. Studies of the US population exposure to dental radiography have been reported since 1964, but these governmental studies have not been summarized with other population–based studies in one publication, or the dose estimated to the brain (5;20;21;27). None of the studies have reported a population-representative estimate of the dose to the brain, only individual studies using phantoms, and none have shown the trends of the doses over time. In addition, no study has investigated what part of the meninges of the brain may receive the largest doses. Furthermore, since the skull is a highly complex anatomic structure with air-filled sinus cavities, thick bony structures, and differing thicknesses of soft-tissue, use of standard radiation dose reference tables are rendered too inaccurate to estimate dose.

Because of these uncertainties, and the need to estimate these absorbed doses for an ongoing study of the risk factors for cranial meningioma, a type of benign brain tumor, our aim was to estimate the population-representative dose to the cranial meninges for the most common types of intraoral dental radiography –single periapical (PA), bitewings (BW) and full mouth x-ray (FMX) -- since 1920, and how these doses have changed over time. These changes over time were likely the result of concomitant changes in how the dental x-rays were taken, otherwise known as technical factors, such as film speed, kilo voltage, size of the x-ray beam, the filtration of the x-ray beam, etc.

Methods

General approach for estimation of dose

The general approach we used to estimate the absorbed dose to the brain from dental radiography for the US population was to perform several separate estimations, based on existing information, and then link them together to reach this final goal (figure 2.1). First, the literature was searched for population - based studies that measured the x-ray machine radiation output and accompanying backscatter radiation, or entrance skin exposure (ESE) from intraoral dental radiography over the 73 year time period. Second, the technical and machine factors used in intraoral radiography were abstracted and estimated using published studies over this time period. Third, studies using phantom heads that reported both the entrance skin exposure and brain-meningeal doses (at the pituitary) from these radiographs were found so that the skin exposure studies could be related to the brain doses in percentages of penetration. Fourth, the literature was searched for studies that reported the doses to the brain in regions besides the pituitary gland from these types of radiography, so that the regions of the meninges with the highest levels of exposure could be located. Finally, the results of these earlier steps were integrated to allow estimation of the population dose distribution to specific brain regions of high exposure. In order to perform these estimations, we supplemented published estimates with measurements of the absorbed dose to the brain using a tissue equivalent skull.

General literature search strategy

We looked first at all of the references that two previous papers, Preston-Martin et al and White, had cited in their study estimating the dose to the parotid gland, and identified the most commonly used MeSH headings from these pertinent articles (12;24). We then performed computerized searches of the PUBMED database from 1965 to 2000 using the terms *radiography, dental* AND *radiation dosage* OR *radiometry* (n=~800). We also performed manual searches of *Index Medicus* and *Index to the Dental literature* under the term " *roentgenography, dental* " from 1930 to 1965. Since much of the work about the radiation exposure to the population has been done by the US Government, we also searched the National Technical Information Service (NTIS) database of government publications using the terms *dentistry* or *dental care* AND x *rays or radiography, nationwide* and *radiography* OR *x rays*, *NEXT* and *radiography* or *x rays*. Relevant information in books was found by performing searches of OCLC WORLDCAT using the textwords *radiography, dental* OR *dental x-rays.* Finally, the reference sections from all of the retrieved articles were scanned for additional pertinent articles.

Inclusion criteria

Studies needed to be published in English or have an English abstract, and have information about skin exposure or dose to the brain from dental intraoral radiography. Surveys about the technical factors for intraoral radiography were also included, e.g. the percent of dentists using short cones, using paralleling technique or machine half value layer of aluminum filtration (HVL). Half-value layer is the amount of material that reduces the intensity of an x-ray beam by half. HVL is commonly expressed as a thickness of metal, such as aluminum (Al) in dental radiography (e.g. HVL of 1.5 mm thickness Al).

Units

All radiation dosages were converted to the newer SI units of radiation absorption, the Gray (Gy), where 100 Rad = 1 Gy. Roentgens of radiation emitted were converted to Rad using the conversion factor of 0.92 (28). Since the conversion to dose equivalent units for x-rays is multiplied by 1.0 (1 Gy = 1 Sievert, (Sv)), only the absorption values in Gy are reported, although they generally are equal to Sv.

Human skull phantom

A human skull encased in tissue-equivalent clear Lucite *(Picker International, Inc. 595 Miner Road, Cleveland, Ohio, USA 44143)* was used to estimate internal brain doses that were unavailable from the literature. We drilled two 2.1 cm holes vertically from the superior surface of the phantom into the regions of the sella turcica, and into the infratemporal fossa. The correct placement of the holes was verified on lateral and AP skull films. X-ray dosimetry was performed with a MDH1515 dosimeter using an MDH model 10X5-180 ion chamber (paddle chamber) (Radcal Corporation, Monrovia, CA). The meter with an ion chamber was inserted into one hole, while the plug of skull and plastic was reinserted into the unused hole. Measurements were done three times, and we took the average of these three measurements. The range of measured doses was always less than 10% of the average value from the lowest to highest. Skin dose was measured in air, and with ThermoLuminescent Dosimeters (TLD) (Siemens Corp.). Single molar, premolar and incisor periapical radiographs for both maxillary and mandibular teeth, along with 4 bitewing and 20 film full mouth x-rays were simulated using bisecting and paralleling techniques.

Detailed methods for each estimation step

Step one –estimation of the entrance skin exposure in the US population,

We searched and read all articles that contained information about skin exposures from intraoral radiography including full mouth survey, bitewings or single periapical films. We abstracted or calculated the mean, median, highest and lowest dose of the entrance skin exposure from these studies. We also used information about the skin exposure from the Washington State Department of Health, X-ray control section from a database of all 13,650 inspections of facilities with dental radiography performed in the state from January 1991 to April, 2000. For years before 1956, we could not locate any population-representative studies, so we estimated the lowest doses by assuming that there were some dentists that used the fastest available film, and purchased the most advanced dental x-ray units with the least amount of radiation output at any given time period. For example, in 1925, Kodak first released the original *Radiatized* film, which was twice the speed of Kodak *Regular film*, and General Electric first sold an x-ray machine (CDX- E) with increased aluminum filtration in 1933 (29), each time allowing for a large reduction in dose. To calculate the upper limit of radiation exposure before 1956, we made the plausible assumption that was supported by later surveys (27;30) that some dentists would over-expose (by factors of 1.5 to 3) and under-develop the slowest available dental films until these films were discontinued and dentist's supplies were depleted (about 1954 for Kodak *Regular* film). In addition, we assumed that some dentists would continue to use equipment without additional aluminum filtration and increased collimation until they were required to make changes by the state governments (over 40 states enacted laws by about 1965.

Step two – estimation of population-representative technical factors in intraoral radiography

We found and abstracted studies and literature that reported technical factors used in intraoral radiography. These factors included the half value layer of filtration in millimeters of Aluminum (HVL), peak kilovoltage (kVp), diameter of the radiation beam, technique used (bisecting or paralleling), type of positioning device used (pointed cone, short cone, or rectangular), film to the radiation source distance in centimeters (FSD), and film speed, using the ANSI speed rating. Since the first population-representative surveys of technical factors were not available until 1956, we used manufacturers' published values for the most common machines used in the earlier decades. We estimated the prevalence of the most common dental x-ray machine models and created a weighted average of these models to estimate the proportion of technical factors for each year. All of these technical values were plotted and a best-fit line was created and values estimated for each calendar year.

Step three – Relationship of surface dose to brain and meningeal tissue dose

We located all studies that reported or allowed calculation of both the entrance skin exposure (ESE) and brain dose from any type of intraoral radiography. This allowed the estimation of the percentage of radiation penetration to the brain for each technique, defined by dividing the brain dose by the ESE. Full mouth survey film counts (range 11 to 25 Films) were proportionally adjusted to equal an 18-film survey. The data were abstracted for the surface, meningeal/brain dose and also for technical factors that were hypothesized to effect dose from radiation physics: half-value layer of filtration in mm of aluminum (HVL), peak kilovoltage (kVp), the diameter of the radiation beam in cm, whether the positioning indicator device was a pointed cone, open cone or rectangular; if the bisecting or paralleling technique was used, whether the phantom used was a Rando (Alderson Laboratories, Stamford, Conn), Mix-D (a type of tissue equivalent material), wax paraffin skull, cadaver, skull in water or computer simulation; the film to x-ray source distance (FSD); if the target organ was the pituitary gland or the entire brain; whether lead-backed film was used, and if the radiation measuring device was an ion chamber or thermolumiscent dosimeter. Indicator variables were created for the types of phantoms, radiographic technique, type of positioning device, target organ, if lead-backed film used, and if the film survey was for a full mouth survey or posterior bitewings. Univariate and bivariate relationships were calculated, and these variables were plotted versus the penetration percent (brain dose/ ESE x 100) to test assumptions of linearity.

Next, the variables were entered with both forward and backward elimination methods of linear regression to find the most parsimonious model that did not have high levels of collinearity. Second order functions were also used for the most important variables. Regression diagnostics were used to find possible outlier values. Calculations were done using SPSS version 10.0 and 11.0 (SPSS corporation, Chicago, 2000, 2001), and Microsoft Excel 2000 (Microsoft Corporation, Redmond, WA). Since many of the published phantom studies performed multiple trials of different technical factors, some of these trials were correlated with each other. Thus, generalized estimating equations in Stata 7.0 (StataCorp LP, College Park, TX) were used to find the most parsimonious regression models to test the effect of the correlations. Since the coefficients were unaltered, although the variance of the coefficients increased, no further calculations were done with Stata. Then, technical factors estimated in step 2 were inserted into the regression equations for the corresponding year and the percent penetration was tabulated from 1920 to 1993.

Step four – Radiation dose distribution to cranial meningeal tissue

Since the adult brain (and meninges) are oblong or spherical objects surrounded by an irregular bony case, finding regions with the highest doses from these different radiographic techniques is challenging. We looked through all retrieved articles for those with information about the dose distribution of intraoral radiography within the head. Using the pituitary gland (sella turcica) as a reference, we calculated the proportion of the absorbed dose at other sites within the brain, meninges and cervical spinal cord in divided by the pituitary reference dose to ascertain if other areas had higher or lower doses than the sella region.

Step five – Dose to the brain and meninges of the US population

We estimated the population based dose to the brain from dental intraoral radiography by two methods: First, by multiplying the entrance skin exposure from the best fit line (step 1) for any given year by the percent penetration to the sella turcica, determined by the penetration regression equation from step 3 for that year and the technical factors from step 2. Second, we estimated these doses by using the few studies (although not on live humans, and not population-based) that directly estimated the dose to the sella turcica. Regression models were determined using the same methods as for Step 2, although the dependent variable now was the dose to the brain in microGray (μ Gy), instead of percent penetration. Studies were limited to those with values for full mouth surveys. Technical factors from step 2 were again inserted into the regression equations to estimate the brain dose for each calendar year. Finally, the pituitary doses were multiplied by the proportion lesser or greater determined in step 4 for other anatomic regions in the brain and meninges.

Step six: Estimation of the dose fraction for 1 periapical and 4 bitewing radiographs

Since the number of films taken in a bitewing or full mouth survey can vary, we located and summarized studies that surveyed dentists to determine the average number of films for these two types of procedures over time (15)(21;31) (32;33) (34). We then compared our own phantom study with those of others (35;36;37) to calculate the proportionate dose to the pituitary meninges for radiographic surveys less than an 18 film full mouth survey (1 periapical film, 4 bitewing survey and different single film projections (anterior periapical vs. posterior periapical.

Results

Estimation of skin dose to the US population from one intraoral radiograph in uGy

Table 2.1 is a table of the mean, median and range of entrance skin exposure from a single intraoral dental radiography of a molar tooth, from 1920 to 1993. The 1920 – 1941 values are from phantom reconstructions published in 1981 (38). The values from 1952 to 1955 are from published studies of the entrance skin exposure from molar periapical or bitewing radiographs of small number of patients (39;40); and the ranges are estimated from the types of film and machines available (29;38;41). The values from 1956 to 1993 are from representative surveys of the US or of entire cities or states, with the means and medians indicated from these studies(5;20;27;32;39;42;43;44;47-52).

Figure 2.2 is the corresponding graph of the mean, highest and lowest values of the entrance skin exposure from a single intraoral dental radiography of a molar tooth, from 1920 to 1993 plotted with best fitting lines. This graph shows an approximately 130-fold reduction in the entrance skin dose from 281,000 μ Gy in 1920 to 2170 μ Gy in 1993.

The population distributions of entrance skin exposure for any given year that are available (5;53;54) show a generally normal distribution, but with a long, skewed tail of higher dose exposure. The high and low values vary by over 4 fold in the estimated early years to 40-50 fold during and after the middle 1950's, when observed values in dental offices first became available.

Dental x-ray technical factors from 1920 to 1993

Table 2.2 shows the estimated mean technical factors for intraoral radiography from 1920 to 1993. The sources of the information are: 1) 1920 to 1956 values are from a single reconstruction and data from manufacturers (5;38), (29;41); 2) early surveys of select groups (39;39;54); and 3) population surveys from 1956 to 1993 (26;26;27;42;50;55-61), 35). The table shows a steadily increasing HVL for dental x-ray machines from 0.4 in 1920 to 2.3 in 1993, with a rapid increase in the 1960's. The beam diameter slowly decreased from 9.2 cm (3.6 in.) in 1920 to 6.3 cm (2.5 in.) in 1993. The position indicating devices began in 1920 with about half open, round cones, and then pointed cones prevailed, until the 1960's when round cones became more prevalent, and recently, a few rectangular devices have been used. The KvP showed a gradual increase from 58 in 1920 to 73 in ~1980, and a slight decrease to 69 in 1993. A change from bisecting to paralleling technique was also seen, beginning in the 1960's.

Models of penetration to the brain from intraoral radiography

Table 2.3 is a compilation of regression models estimating the percent penetration of radiation from the entrance skin exposure of intraoral radiography to the pituitary gland, and the estimated penetration values after inserting the technical factors for the years 1920 to 1993. These data were abstracted from 71 separate dose measurements published in 16 studies; all using humanoid head phantoms [see Appendix I for a table of these values]. The penetration to the brain ranged from a low of 0.17% for 1920 up to 1.8% for 1970. The half value layer of aluminum in mm (HVL) was the variable most strongly associated with greater penetration to the brain. The simplest models were generally close to the most complex models in the penetration estimates, although models with the variables bisecting technique and cone type tended to create higher values of penetration during the 1960's and 1970's (see Figure 2.3). To check these estimations, we plotted the percent penetration vs. the estimated year of technique; these values are presented and are close to the penetration figures from the regression models. Potentially confounding variables, such as the type of phantom, and type of radiation measuring device, did not substantially alter the estimates.

Three-dimensional dose distribution to the brain and meninges

The sella turcica has historically been a common location for dosimeters. We found 10 studies that measured the dose to the brain in different locations for full mouth (62-70) and bitewing radiography (table 2.4). The greatest dose for full mouth surveys (or bitewings) is in the midline of the brain, since all the multi-film dental techniques are symmetric around the subjects' midline; this maximal dose is slightly further posterior and inferior from the sella turcica, approaching the foramen magnum, in the clivus region. The percentage of doses in this region is about 1.5 to 5+ times higher than in the sella turcica region. Figure 2.4 shows a saggital view of the dose of a 2 bitewing survey simulated by Monte Carlo computer simulations using a short round cone (66). Highest doses for the brain and meninges are close to the base of the skull, in the foramen magnum region and outside of the brain in the cervical spinal cord region of C-2.

Population-representative dose to different parts of the brain from intraoral radiography

Table 2.5 shows the mean radiation dose to the sella and the clivus regions of the meninges for single periapical, bitewing and full mouth radiography, as calculated from the values in tables 2.1, 2.2, 2.3 and 2.4 in microGy from 1920 to 1993.

Alternative estimation: models of mean radiation dose to the sella from intraoral radiography

These data were abstracted from 71 separate dose measurements published in 16 studies using regression methods similar to those for the percent brain penetration estimations . The simplest models of HVL and HVL-squared estimated the meningeal pituitary values to be 12000 microGy in 1920 down to 550 microGray in 1993. More complex models, adjusting all values to the Mix-D phantom or computer simulation showed slightly different values.

Figure 2.5 shows the mean dose for a single periapical, 4 bitewings, and full mouth survey over the time period 1920 to 1993, for both the dose at the sella and at the clivus region. The inset graph shows the doses on a logarithmic y axis scale.

Discussion

In this study, we estimated the population dose to the human body from dental radiography over this 73 year time period, showed trends over time for brain and meningeal doses, and showed which areas of the brain and cranial meninges have the highest doses. The results show large, graded reductions in the absorbed dose for dental intraoral radiography that are larger than for any other type of diagnostic radiography (5). This level of reduction has been previously discussed by Richards (38), based on their dose reconstruction study, although only two time points were given (1920, 1980), and these were not based on any representative surveys of dental x-ray usage. These large dose reductions are likely due to increased aluminum filtration, faster, more sensitive film and concomitantly reduced exposure times, decreased size of the beam, and increased collimation (38).

Large variations in dose were noted between dental facilities due to the use of different film speeds, different machines, and different technical factors. The reason why there is so much variation in x-ray doses in dental practices is not well studied, but there is evidence that the year of dentist graduation affects the dose, since dentists commonly purchase x-ray equipment as they first enter dental practice, and keep this equipment for many years, since it does not deteriorate much with use (personal communication, Larry Svare, May 5, 1996) (20). Other demonstrated risk factors for higher exposure in recent years are improper film processing, kilovoltage miscalibration, and use of D-speed techniques with E-speed film, among others (71). We hypothesize that other factors may include whether the dentist is an early or late adopter of new technology (72).

Comparative dose

The highest doses in the meninges indicated in table 2.5 are on or before 1960 and calculated to be 16,818 μGray (16.8 mGy). This is only about one fortieth of the smallest doses (700 mGy) that were imparted to the brain in the tinea capitus studies (2).

However, a radiation augmentation effect has been noted as x-rays pass through the calvarium, so that within the first 10-50 microns of the internal skull wall, there is a momentarily higher dose by a factor of up to 50%, which would correspond to the outer dura mater (73). This transient increased dose would not be measured by the phantom studies, since the dosimeters would need to be very small and would need to be attached just inside of the skull. With a 'worst case' scenario of a dentist using the slowest speed x-ray film, overexposing and under developing x-rays, along with a large number for x-rays taken (20 to 25) for full mouth surveys with retakes, and measuring the absorbed dose in the clivus anatomic region, doses of 170 mGy (0.17 Gy) per 22 film full mouth survey could be achieved. If four full mouth surveys were taken, a dose equivalent of 0.67 Gy to the dura mater in the clivus region is possible. Thus, it may be biologically plausible that meningiomas could be have been caused by early dental radiographic procedures if multiple full mouth series were taken within the highest dose range. Although ionizing radiation is thought to be cumulative in its possible ill effects, fractionating the dose into multiple smaller exposures can decrease the overall effect by approximately one-half. Such high dental exposures, however, would be rare, since these values are in the 99^{th} percentile of the population-representative dose distribution in 1960, and 16 full mouth surveys would be required if the median dose in 1960 was given instead. The highest dose scenario for the year of 2002 would be a 4 mGy (0.004 Gy) dose to brain per full mouth survey, which corresponds to 250 present day full mouth surveys to reach a dose of 0.50 Gy.

Regression models showed an unexpected 'bump' of increased penetration in the 1960's, and this time period of increased penetration was apparently due to the predominant bisecting technique with wide diameter tubes, use of pointed cones, and still relatively low filtration that allowed the spread of the primary beam of radiation into the anterior and inferior aspects of the brain.

Limitations

Some of the limitations of this analysis should be noted. Many of the technical factors estimated from 1920 to 1953 are uncertain, especially beam diameter and HVL, since only a handful of studies before 1950 have been published. In addition, all the internal organ estimates are from various types of models of humans, or phantoms. However, the regression analyses showed that the variation in dose between phantom types was small, except for one study (40), and they compare well to cadaver and computer simulation based on human anatomy (34). Differences in sizes of people, male and female differences (20), etc, could alter the dose. Whether the dose to the brain and meninges in children would be substantially differ from the adult dose is not clear, although it may be higher, since more of the skull is in the field of exposure, and the tissue thicknesses are smaller. This is partially offset by the lower doses (about 25% less), that are imparted on children to obtain radiographs of optimal diagnostic quality. In addition, regional differences exist in these exposures, and the latest (1999) National Exposure of Dental X-ray Trends (NEXT) survey showed some variation in the mean molar ESE from 1570 μgray (East Coast) to 2234 μgray (Midwest) (personal communication, David Spelic, PhD, August 5, 2002). We may also be wrong about the penetration to brain values, and the models chosen may not reflect the actual doses delivered to the meninges. However, our second method of estimation of directly determining the meningeal dose was with 20% of the calculated values, except from 1965 to 1975, where it was substantially less. In addition, a simple method of plotting the dose at the sella turcica by the technique year also yielded a similar looking curve but without the 'bump' in the 1960's.

Strengths

Some of the strengths of the present investigation is the ability to relate the phantom studies to the population-representative studies, and estimate the dose to internal organs such as the meninges and brain. In addition, the estimation of the population-representative ESE allows dose reconstruction of intraoral radiography doses to other radiosensitive structures, such as the thyroid and parotid glands, if these values are multiplied by the percent of penetration to these organs. These organ penetration percentages could be determined similarly from phantom studies. Most previous studies used the best available techniques at the time, not what is commonly used in practice, thereby limiting their generalizability. We also employed exhaustive searching methodology, so that it is unlikely that we missed many existing studies on this subject. Furthermore, the regression models found are supported by previous dose estimation work, where the HVL and beam diameter are known determinants of radiation absorbed dose in radiology (28).

In summary, we have shown that there have been large but gradual dose reductions in the population-representative dose to the brain and meninges from dental intraoral radiography, including full mouth, bitewing and periapical radiographs. Large variations in the doses imparted from one dental facility to another have occurred. And finally, multiple full mouth survey radiographic exposures in 1920's to 1960's from offices with the highest values could plausibly have caused brain tumors, although at today's lower doses, one would need several hundred full mouth x-rays to reach this same dose level. Although doses from dental radiography are now much lower, they still may be tumorigenic on a population basis, because of the large number of dental radiographs taken, and the prevailing theory that there is no lower threshold of a safe dose (74). A small number of any type of tumors related to dental radiographs could still be expected to occur, and these risks have been calculated in the range of between 1 to 4.5 fatal neoplasm for every million dental full mouth surveys for 1992, using general formulas from the International Commission on Radiological Protection (24). However, other present day diagnostic radiography, such as head CT, is currently in the absorbed dose to the brain of 34 to 54 mGy (75) and its use should be carefully monitored.

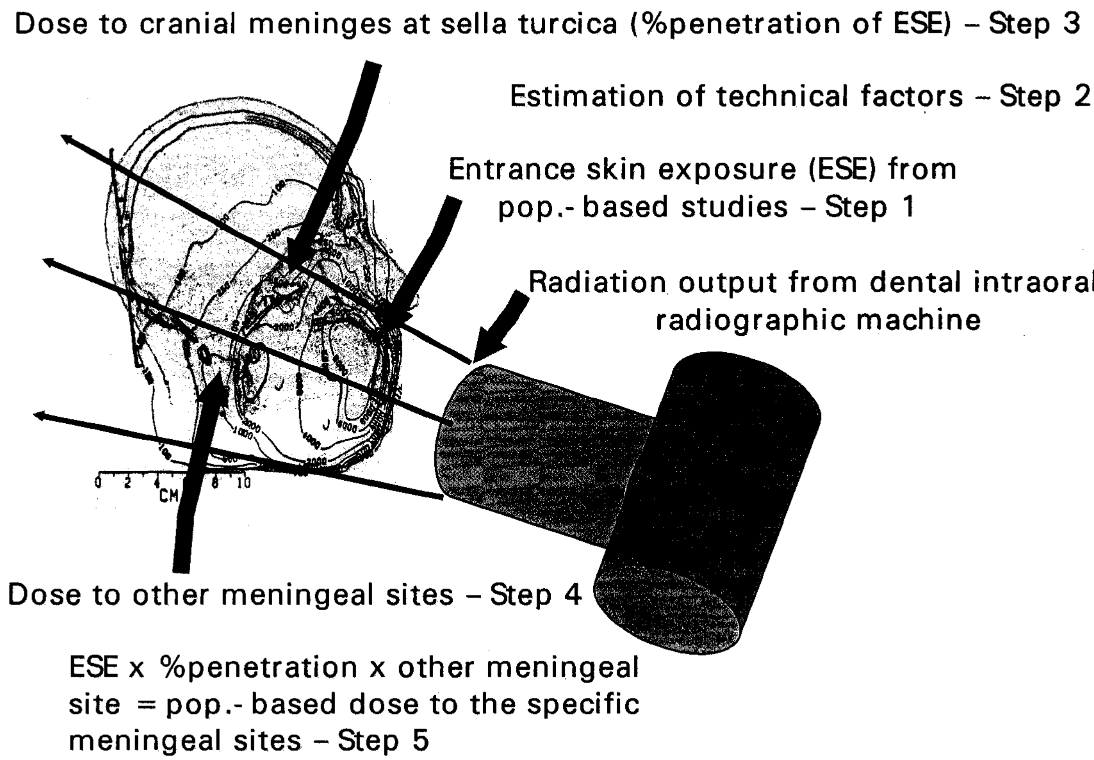


Figure 2.1 – Strategy to estimate radiation dose to the cranial meninges from dental radiography.
First, the entrance skin exposure from dental intraoral radiographs was determined; second, technical factors over the time span studied were estimated; third, the dose to the cranial meninges at sella turcica was calculated; fourth, the proportional dose to other cranial meningeal sites was determined; fifth the entrance skin exposure, percent penetration and any proportional factor for other anatomic sites was multiplied by each other to yield the population based absorbed dose to the cranial meninges.

Figure 2.2 Entrance skin exposure from one molar periapical radiograph to the facial region, 1920 to 1993. This figure, which is step one in figure 2.1, shows the high, low and mean entrance skin exposure in microGray over this 73 year time period. The exposure trends are best-fit lines created using polytomous linear regression between the dose estimates depicted as boxes from published studies. The dose estimates depicted as stars are not included in the best fit lines, either because they are not representative of the population or were not were not as representative of the techniques at the time. XES denotes the X-ray Exposure Study, and NEXT is and acronym for Nationwide Exposure in X-ray Trend studies. "X" data points depict the lowest dose values, while the "◊" represent highest dose values in any one given year.

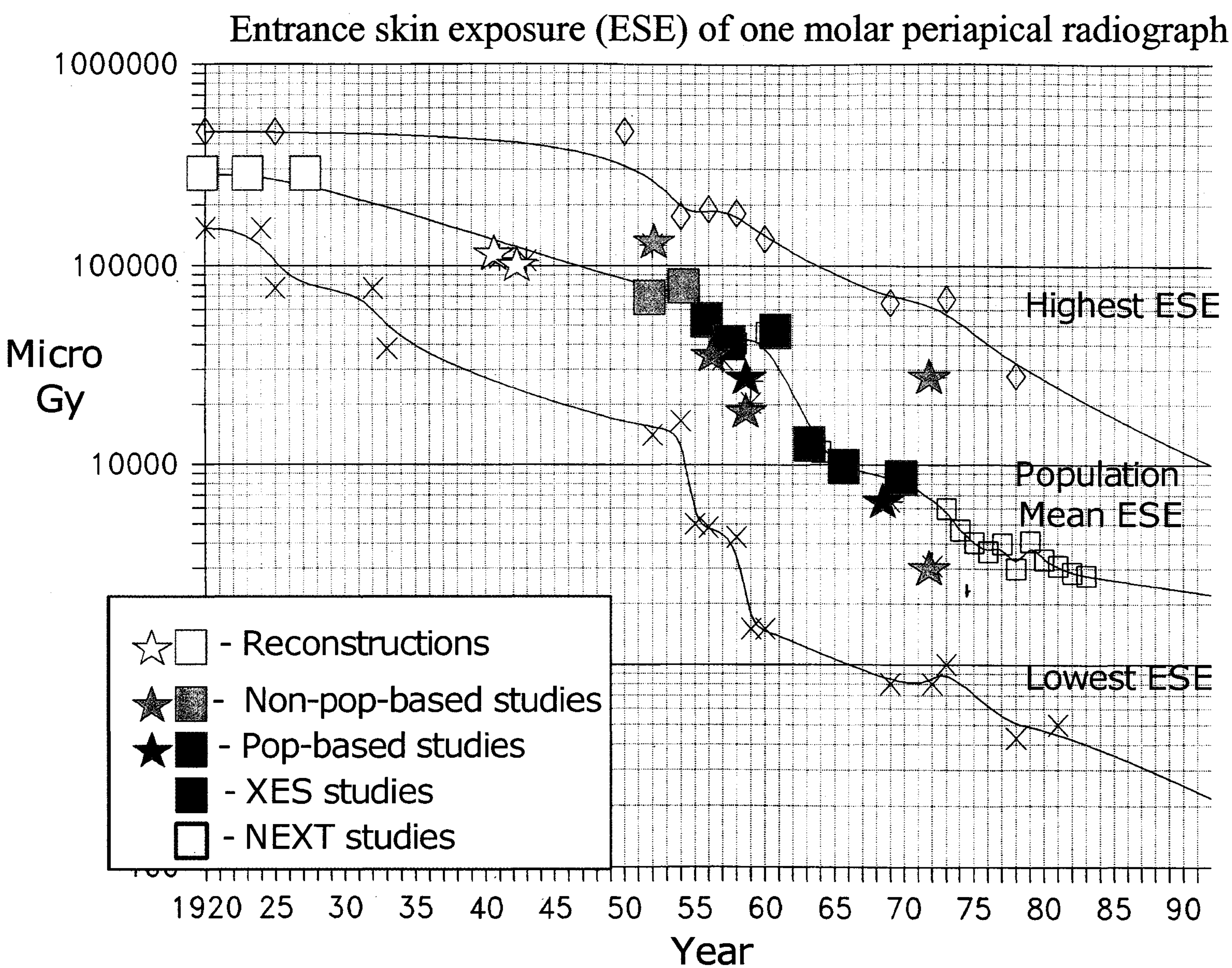
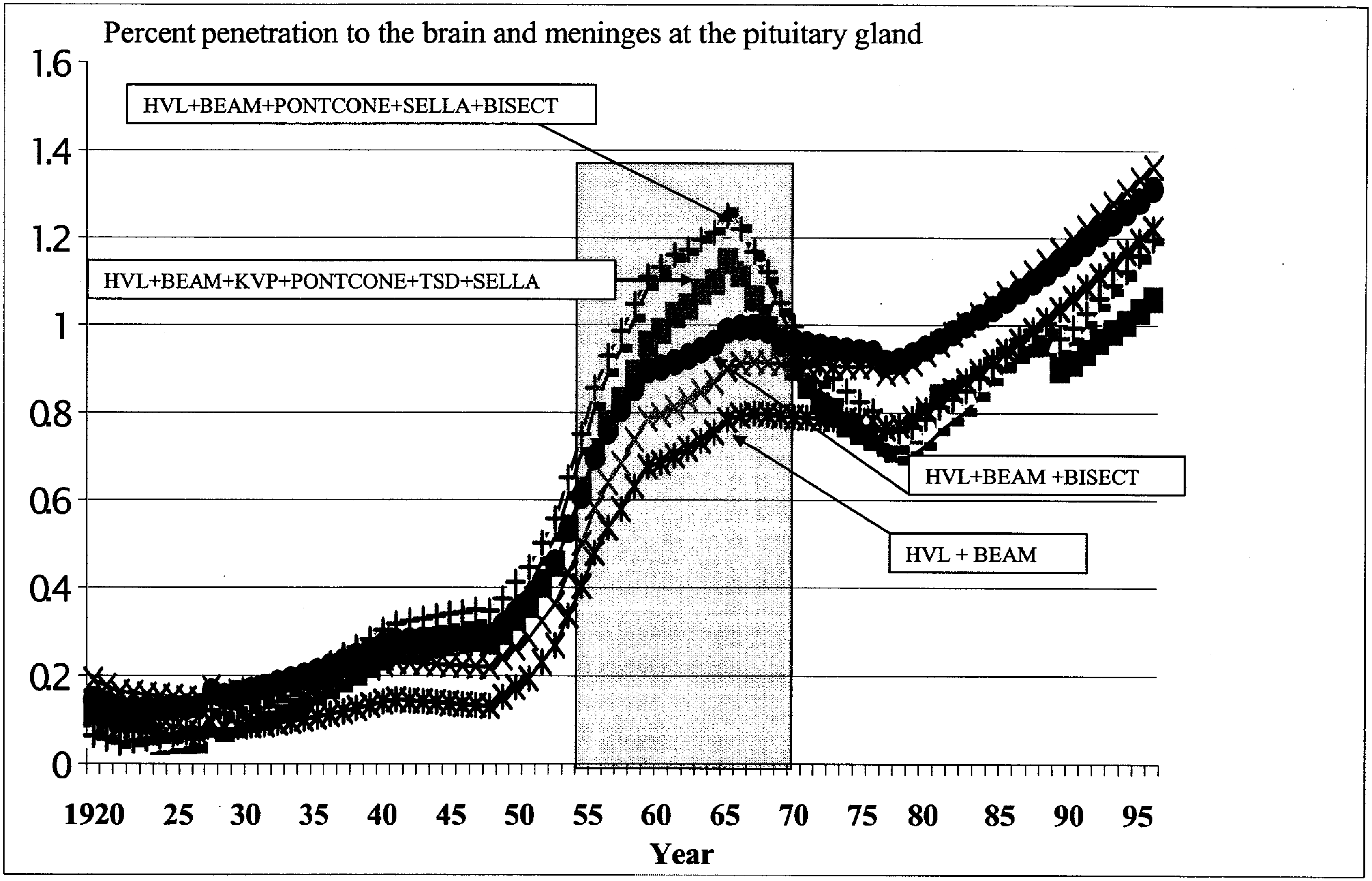

Entrance skin exposure (ESE) of one molar periapical radiograph
1000000
100000
10000
Micro
Gy
Highest ESE
Population
Mean ESE
Lowest ESE
- Reconstructions
- Non-pop-based studies
- Pop-based studies
- XES studies
- NEXT studies
1920
25
30
35
40
45
50
55
60
65
70
75
80
85
90
Year

Figure 2.3 – Radiation percent penetration to the brain from dental radiography, 1920 to 1993. Ionizing radiation percent penetration to the brain and meninges at the pituitary gland from 1920 to 1993. Various models are illustrated. The curves with the lowest values had only HVL (HVL) and beam diameter (BEAM) in the models; the highest curves have HVL, beam diameter, bisecting vs. parallel technique (BISECT), and pointed cone (PONTCONE) in the models. These models suggest that the unexpected increased penetration from 1955 to 1970 was due to relatively low HVL, large beam diameter, bisecting technique and use of pointed cones. Interestingly, US government sponsored programs of reducing radiation output from dental x-ray units by increasing HVL, reducing diameter and phasing out pointed cones began in 1960 and were generally completed by 1970. Other variables included in models are TSD for target to surface distance, KVP for kilovoltage, and SELLA for using sella turcica as the reference.


Percent penetration to the brain and meninges at the pituitary gland
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
HVL+BEAM+PONTCONE+SELLA+BISECT
HVL+BEAM+KVP+PONTCONE+TSD+SELLA
HVL+BEAM +BISECT
HVL + BEAM
1920
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
Year

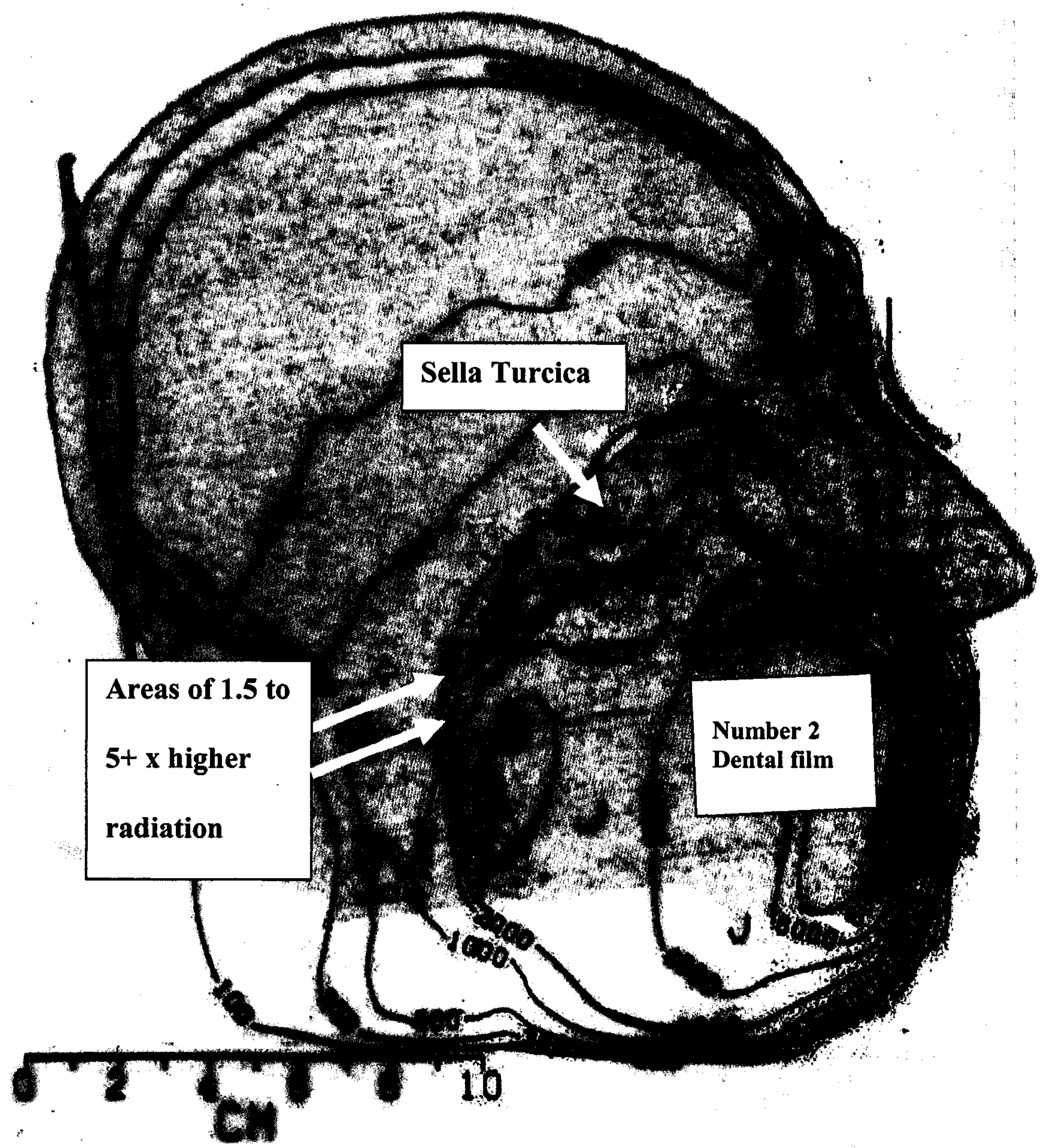


Figure 2.4- CT saggital view of human head phantom with radiation doses from two bitewing radiographs.

This computed tomographic (CT) saggital view of a human head phantom is overlaid with regions of higher radiation from intraoral radiography – 2 bitewing radiographs taken with a short cone – as determined by a Monte Carlo simulation by Gibbs. Please note that the skull presented is scaled to the same dimensions of the isodose radiation curves, but it is not the skull on which the simulation was completed. Adapted and modified from Gibbs (1984), with permission. Radiation units are in microGray.

Figure 2.5 – Mean radiation dose to the clivus and sella regions of the cranial meninges, 1920 to 1993. The figure shows the mean ionizing radiation dose to various regions in the cranial meninges from a single full mouth series of x-rays over this 73 year time period. The purple line shows the dose to the clivus region, which is generally the highest dose for the cranial meninges. The dark blue line shows the mean dose to sella turcica from full mouth series using a nine variable model from table 2.3, and the pink line shows a more enhanced 11 variable model from table 2.3. The yellow and blue lines show mean doses for four bitewing and one periapical x-rays. The inset figure shows the same dose values, but on a logarithmic y-axis scale. Note that all of the doses are roughly proportional to each other.

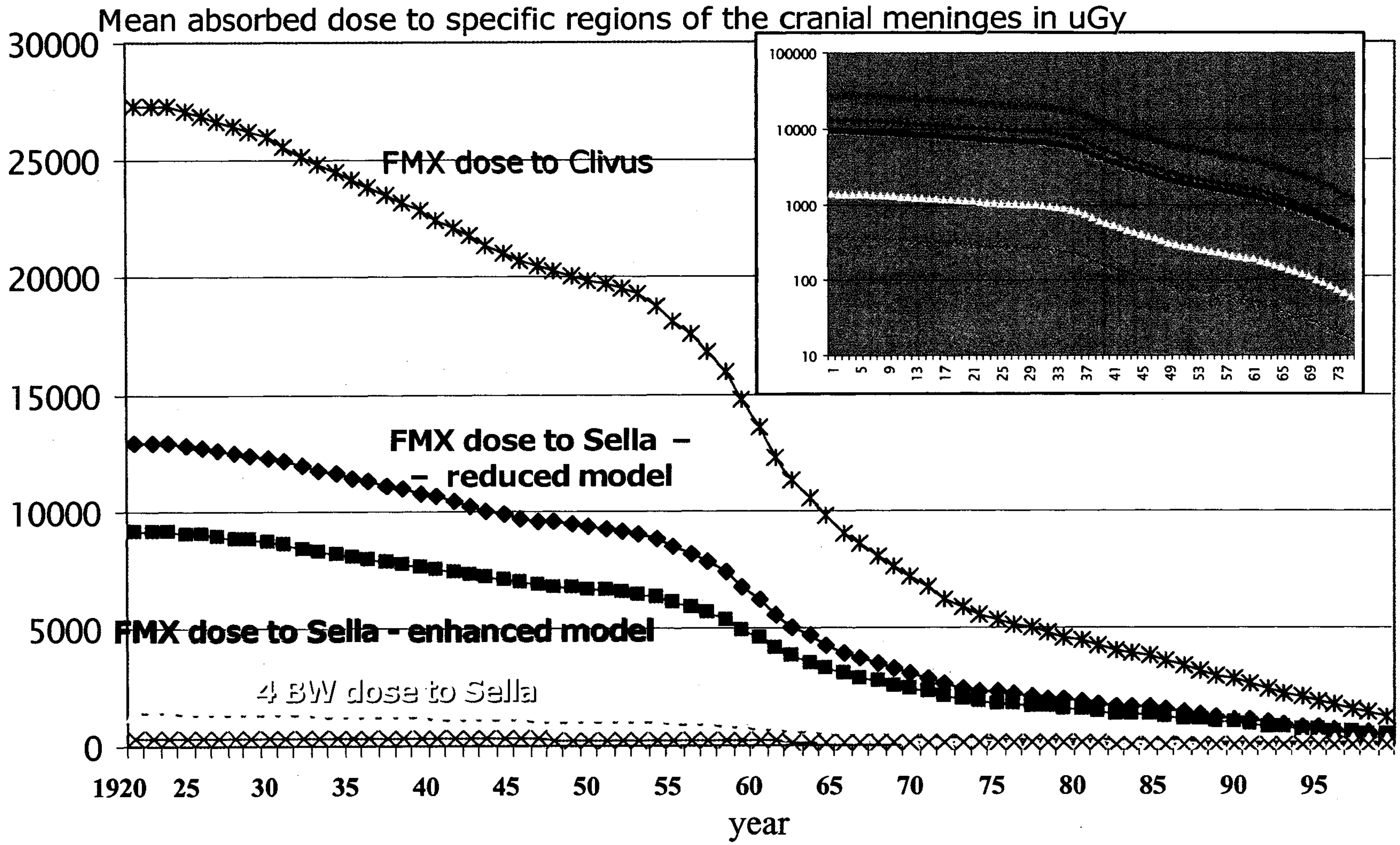

Mean absorbed dose to specific regions of the cranial meninges in uGy
30000
25000
20000
15000
10000
5000
0
1920 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
year
FMX dose to Clivus
FMX dose to Sella – – reduced model
FMX dose to Sella - enhanced model
4 BW dose to Sella
100000
10000
1000
100
10
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73

Table 2.1 Mean, median and range of entrance skin exposure (ESE) from one molar periapical radiograph, 1920–1993 in microGray.

First Author	Time Period	Subjects	Region	Type of sample	No. of subjects	No. of x-ray units	ESE* Mean		ESE Median		ESE Low	ESE High
Richards	~1920	RANDO phantom	Michigan	none	1	1	281,850	$			*153,000*	*459,000*
	1925	new faster film (original *Radiatized*)	United States	na							*76,500*	
Richards	~1927	RANDO phantom	Michigan	none	1	1	271,400	$				
	1933	first dental x-ray with 1.5 mm Al. filtration	United States	na							38,250	
Richards	~1940	RANDO phantom	Michigan	none	1	1	100,364	$				
Richards	~1941	RANDO phantom	Michigan	none	1	1	97,018	$				
Nolan	1952	dental patients	San Francisco	convenience	10	3	74,730	**	112,000		14,000	126,000
Todd	1954-55	wax paraffin phantom	Kentucky	convenience	na	23	76,400	**	86,300		16,900	175,000
	1955	new faster film (Improved *Ultraspeed*)	United States	na							5,000	
Gorson	1956	ion chamber	Philadelphia	ns	na	56	55,200	#	34,000		4,800	189,600
Yale	1957-58	dental patients	Chicago	random	122	122	33,800	**&$				
Richards	1958	masonite phantom	Oakland	random	na	54	44,200				4,300	181,000
Crandell	1959	ion chamber	North Carolina	convenience	na	117	20,400	#			*1,500*	*50,400*
Barr	1959	dental patients	Boston	random	200	200	26,400	&	20,300		1,500	135,000
Yale	1959-60	dental patients/dosimetric film	10 States	random	1955	1955	50,000	#**				
Gitlin	1964	probability sample of US civilians	United States	random	2576	ns?	11,491	$			1,000	52,000
Lubenau	1966	dental offices	Pennsylvania	50% sample	na	2168	9,292	$			1,000	33,000
Travis	1969	dental offices	Rhode Island	20% sample	93	147	10,000				1,000	82,000
Wash State	1969	dental offices	Wash. State	20% sample	na	400	6,495	$	4,500	**	800	65,000
US Gov't	1970	probability sample of US civilians	United States	random	4897	ns?	8,464	$				
Wash State	1973	dental offices	Wash. State	15% sample	na	300	3,091	$	2,100	**	800	27,500
Wochos	1972-74	dental facilities	38 States	random	ns	1408	5,980	$	4,500		1,000	68,000
US Gov't	1974	dental facilities, weighted by workload	35 States	random	ns	1052	4,663	$				
US Gov't	1975	dental facilities, weighted by workload	35 States	random	ns	1796	4,045	$	~3,500		~500	20,000+
US Gov't	1976	dental facilities, weighted by workload	36 States	random	ns	2311	3,621	$				
US Gov't	1977	dental facilities, weighted by workload	32 States	random	ns	1766	3,976	$				
Manny	1978	dental facilities, weighted by workload	28 States	random	ns	1374	2,981	$	2,512		432	27,986
US Gov't	1979	dental facilities, weighted by workload	25 States	random	ns	1232	4,087	$				
US Gov't	1980	dental facilities, weighted by workload	18 States	random	ns	1036	3,304	$				
US Gov't	1981	dental facilities, weighted by workload	15 States	random	ns	1267	3,072	$				
	1981	New faster speed film (*Ektaspeed*)	United States								500	
Johnson	1982	dental facilities, weighted by workload	~38 States	random	ns	~1100	2,852	$	~2,300	**	500	>10,000
Johnson	1983	dental facilities, weighted by workload	~38 States	random	ns	~1100	2,760	$	~2,500	**	500	>10,000
Conway	1993	dental facilities, weighted by workload	~38 States	random	ns	316	2,170	$	1,812		202	9,200

Table 2.1 (continued).

Legend

*	ESE for a single posterior bitewing radiograph unless otherwise noted
1	ESE values in microGray (uGy) absorbed dose to the skin in the maxillary facial regions unless otherwise noted
2	italics denote low estimated values assuming no retakes and underexposing of films by 50% exposure time
3	High estimated values assuming retake rate of 20% and overexposing of films by 40% exposure time
#	absorbed dose from backscatter added to this value
**	calculated by present authors from data presented in paper
&	ESE for a central incisor exposure
$	absorbed dose to the skin converted from Roentgen (R) to Gray (Gy) by multiplying value by 0.92
?	ESE for a molar periapical exposure

Table 2.2 Technical factors for dental radiography in the US, 1920 to 1993.

Technical factor	1920	1930	1940	1945	1950	1955	1960	1965	1970	1975	1980	1985	1990	1993
mean HVL (mm) from literature	0.40				0.8		1.4				1.96	1.36		2.3
mean HVL (mm) from best fit line	0.40	0.51	0.67	0.75	0.80	1.00	1.38	1.62	1.81	1.90	1.98	2.11	2.25	2.34
Literature source	Richards, 81				Nolan, 53 & Jacobson 52		Manny pg 17		XES 70 & Johnson 86		NTIS, 84	Goren, 89		Next 93
mean beam diameter (cm) from literature	9.19					7.50	8.00	7.59	7.29		6.60			6.35
mean beam diameter (cm) from best fit	9.19	8.90	8.56	8.49	8.15	8.00	7.83	7.56	7.26	6.98	6.70	6.58	6.52	6.48
Literature source	Richards, 81					Gorson, 56	Bjarngard, 60	Gitlin, 66	XES 70 & Johnson 86		NEXT, 84			est
dentists using bisecting technique best fit	100%	100%	100%	100%	99%	99%	98%	86%	76%	69%	63%	57%	50%	48%
dentists using paralleling technique best fit	0%	0%	0%	0%	1%	1%	2%	14%	24%	31%	38%	44%	50%	52%
dentists using bisecting technique from literature					99%			93%						48%
Literature source	est	est	est		Fitzgerald, 7			Dental survey, 62						Bohay, 94
dentists using pointed cone – best fit line	60%	70%	90%	93%	95%	94%	93%	90%	66%	41%	22%	16%	8%	9.0%
dentists using pointed cone from literature							92%	89%	64%		19%		15%	18.0%
dentists using round cone open	40%	30%	10%	8%	5%	6%	7.0%	10.0%	34%	59%	77%	84%	88%	86%
dentists using rectangular open	0%	0%	0%		0%		0%		0%		1%		4.2%	5%
Literature source	est	est	est		est		Fess, 70	Fess, 70	ADA, 72		ADA, 82		Kaugars, 85	Nakfoor, 92
mean KvP	60				58.3		63.0				73.1			71.0
mean KvP from best fit	60	58.5	59.7	60.3	60.9	61.5	62.3	64.1	66.7	69.4	72.2	74.2	72.8	71.9
Literature source	Richards, 81				Nolan, 53		Barr, 60				Kaugars, 85			NEXT, 93
Distance from film to source (cm) (FSD)	18						20.35				?	20.1		
FSD best fit	16.5	17.3	18.2	18.7	19.2	19.7	20.4	21.2	21.93	22.8	22.86	23.5	23.5	23.5
Literature source	Richards, 81						Barr 60				NEXT, 84	Morley, 85		

Table 2.3 Regression models and percent penetration of radiation to the meninges at the pituitary (sella turcica).

	regression models	Sample size	1920	1930	1940	1950	1960	1970	1980	1990
			percent penetration to sella turcica							
Single variable: mean	"= HVL x .496	70	0..20	0.25	0.33	0.40	0.68	0.90	0.98	1.12
Two variable	"= -4.105 + (HVL x .425) + (Beam x .985)	70	0.20	0.15	0.16	0.15	0.58	0.76	0.69	0.88
Two variable + adjust	"= -4.171+ (HVL*1.007)+(Beam x .358) +(BrainTarget x.665)	70	0.19	0.17	0.21	0.22	0.68	0.92	0.89	1.10
Full model	"= -5.92 + (HVL x 1.16) + all 9 other variables	70	0.17	0.13	0.22	0.28	0.80	1.01	0.69	0.91
Reduced model	"= -4.68+(HVL*1.47)+(Beam Diameter *.224)+(Conepont *.728)	94	0.40	0.48	0.64	0.75	1.47	1.82	1.29	1.33
	" + (Technique*605)+(BrainTarget *1.28) - (Phantom3 *1.78) - (MixD*.263) - (TLD *.704)-(Xrayused*.188)"									
Partial model + adjust. variables.	"= -.0504 +(HVL* .01410) + (Technique *.009870) +	94	0.51	0.58	0.61	1.10	1.53	1.22	1.21	1.61
	"(Beam Diameter*.00560) +(BrainTarget *.0150) - (Phantom 2 *.001114) - (TLD *.006136)]"									
Penetration vs. estimated technique year of study: smoothed line.			0.22	0.35	0.58	0.55	0.95	1.10	1.10	1.40

Variable names:	
Outcome variable	"=penetration to the meninges (sella) or brain dose in uGy / Exposure at skin entrance in uGy"
Main exposure variables	
HVL	Half value layer of filtration in mm of Aluminum
Technique	indicator variable - whether technique used was **parallel** or bisecting
kVp	peak kilovoltage
Beam Diameter	diameter of cone in cm
CONEPONT	indicator variable - whether cone is **pointed** and closed, or round and open
CONERECT	indicator variable - whether cone is rectangular or **round open**
Covariates/Adjustment	
Brain Target	indicator variable - whether target organ is the **sella turcica** or the brain as a whole
TLD	indicator variable - radiation measuring device - chamber or **ThermoLuminescent Dosimeter (TLD)**
MixD	indicator variable - two of two - indicates whether phantom was **Mix-D,** or computer simulation
Phantom 2	indicator variable - two of two - indicates whether phantom was **RANDO,** or computer simulation
Phantom 3	indicator variable - one of two - indicates whether phantom was **Skull in water** or computer simulation
ANTproj	indicator variable - indicates whether the film projection was an anterior film or a **full mouth**
POSTproj	indicator variable - indicates whether the film projection was a bitewing, or a **full mouth**
Xrayused	indicator variable-whether an **x-ray with lead backing used** or not
Legend:	Bold faced text indicates default
	regression models above are from 71 measurement trials with phantoms and different technical factors published in 16 different studies

Table 2.4 Absorbed dose to sella turcica and ratio of dose to other anatomic sites in the brain and meninges

First Author	Pub. year	Type of Radiographic Survey	Anatomic Reference Site (Sella Turcica)	Dose in uGy	Inferior brain sites	Dose in uGy	Ratio Site/ Sella	Other brain sites	Dose in uGy	Ratio Site/ Sella
Winkler	1968	22 film FMX	Sella turcica	*130*	**base of skull C-1**	*460*	**3.5**			
Winkler	1968	22 film FMX	Sella turcica	*24*	**base of skull C-1**	*110*	**4.6**			
Frey	1974	1 molar BW	avg. 4-13 & 4-17	8	**6-13 (foramen magnum)**	**118**	**15**	**5-12 (5 mm below sella)**	**249**	**31**
Frey	1974	1 molar BW	avg. 4-13 & 4-17	4	**6-13 (foramen magnum)**	**126**	**30**	**5-12 (5 mm below sella)**	**234**	**55**
Frey	1974	1 molar BW	avg. 4-13 & 4-17	4	**6-13 (foramen magnum)**	**96**	**23**	**5-12 (5 mm below sella)**	**179**	**43**
Frey	1974	1 molar BW	avg. 4-13 & 4-17	25	**6-13 (foramen magnum)**	**198**	**8**	**5-12 (5 mm below sella)**	**284**	**12**
Frey	1974	1 molar BW	avg. 4-13 & 4-17	18	**6-13 (foramen magnum)**	**140**	**8**	**5-12 (5 mm below sella)**	**298**	**17**
Frey	1974	1 molar BW	avg. 4-13 & 4-17	16	**6-13 (foramen magnum)**	**146**	**9**	**5-12 (5 mm below sella)**	**231**	**15**
Frey	1974	1 molar BW	avg. 4-13 & 4-17	38	**6-13 (foramen magnum)**	**259**	**7**	**5-12 (5 mm below sella)**	**338**	**9**
Frey	1974	1 molar BW	average	16	**Foramen magnum**		**14**	**5 mm below sella**	**259**	**26**
Yulek	1979	18 Film FMX	Sella turcica	*300*	**bulbus/pons**	**350**	**1.2**	**frontal lobe**	**620**	**2.1**
Yulek	1979	18 Film FMX	Sella turcica	*200*	**bulbus/pons**	**340**	**1.7**	**frontal lobe**	**600**	**3.0**
Yulek	1979	18 Film FMX	Sella turcica	*250*	**bulbus/pons**	**300**	**1.2**	**frontal lobe**	**560**	**2.2**
McKlveen	1980	18 Film FMX	avg. E-7 & E-12	*856*	**U-3 (Foramen magnum)**	**3620**	**4.2**	**U-6 (ant. Foramen magnum)**	**10170**	**11.9**
McKlveen	1980	18 Film FMX	avg. E-7 & E-12	*741*	**U-3 (Foramen magnum)**	**5960**	**8.0**	**U-6 (ant. Foramen magnum)**	**21640**	**29.2**
McKlveen	1980	18 Film FMX	avg. E-7 & E-12	*1044*	**U-3 (Foramen magnum)**	**3420**	**3.3**	**U-6 (ant. Foramen magnum)**	**7900**	**7.6**
McKlveen	1980	18 Film FMX	avg. E-7 & E-12	*1983*	**U-3 (Foramen magnum)**	**2720**	**1.4**	**U-6 (ant. Foramen magnum)**	**4270**	**2.2**
McKlveen	1980	18 Film FMX	average	1156	**Foramen magnum**		**4.2**	**Anterior Foramen magnum**		**12.7**
Gibbs	1984	2 BW	Sella turcica	*350*	**clivus**	**850**	**2.4**	**base of skull**	**1000**	**2.9**
Gibbs	1984	2 BW	Sella turcica	*80*	**clivus**	**175**	**2.2**	**base of skull**	**200**	**2.5**
Underhill	1988	18 Film FMX	Sella turcica	*289*	Anterior calvarium	*106*	0.4	Posterior calvarium	*27*	0.09
Underhill	1988	18 Film FMX	Sella turcica	*87*	Anterior calvarium	*25*	0.3	Posterior calvarium	*1*	0.01
White	1991	18 Film FMX	Sella turcica	*410*	Ant.,Post.,Lat. Calvaria	*149*	0.4			
White	1991	18 Film FMX	Sella turcica	*264*	Ant.,Post.,Lat. Calvaria	*40*	0.2			
Tetradis	1995	1 molar BW	sella	*25*	Temporal lobe	*0*	0.00			
Avendanio	1996	19 Film FMX	sella	*342*	anterior calvarium	*165*	0.5	**C-2 vertebra**	**826**	**2.4**
Avendanio	1996	4 BW	sella	87	anterior calvarium	43	0.5	**C-2 vertebra**	**186**	**2.1**
Howley	1968	14 film FMX	Sella	850	Mid brain	580	0.7	**lateral lobe**	**3200**	**3.8**

Legend:
Site/ sella ratios are the specific anatomic site dose divided by the reference (usually sella turcica) dose. Higher ratios show proportionally higher levels of radiation.
Bold-faced type shows higher than sella dosages
Underlined type are averages of multiple lines using slightly different technical factors
Letter-numbers combinations denote standard locations in RANDO phantom heads for dosimeters

Table 2.5 Mean dose in microGray to the cranial meninges at sella turica and clivus from intraoral dental radiography in US, 1920- 1993.

X-ray Type	Target location	1920	1925	1930	1935	1940	1945	1950	1955	1960	1965	1970	1975	1980	1985	1990	1993
1 PA Film	sella	337	221	192	179	200	198	164	196	210	74	57	24	14	14	14	13
1 PA Film	clivus	1,010	663	576	536	601	593	491	587	631	222	170	71	42	43	43	38
4 Bitewing	sella	1,346	884	768	715	801	791	654	783	841	296	226	95	56	57	57	51
4 Bitewing	clivus	4,038	2,652	2,304	2,145	2,403	2,373	1,962	2,349	2,523	888	678	285	168	171	171	153
FMX (18)	sella	8,976	5,896	5,122	4,766	5,341	5,272	4,357	5,115	5,606	1,971	1,508	632	376	379	370	342
FMX (18)	clivus	26,928	7,688	15,366	14,298	16,023	15,816	13,071	15,345	16,818	5,913	4,524	1,896	1,128	1,137	1,110	1,026

Chapter 3: Estimating the true exposure to dental radiography using multiple information sources.

Objective: We hypothesize that the dental record does not list all radiographs that are actually exposed on patients. The primary aim of this study was to estimate the number and type of dental radiographs exposed on a person for common dental radiographic procedures and procedures that are associated with radiographs.

Methods: A flow diagram of actions and decisions in all phases of dental radiography was constructed, and a hypothetical model created. Separate data sources to determine exposed, recorded, stored and billed radiographs included: in-person dentist interview; a mailed survey of dentists, hygienists and assistants; in-office abstracted dental charts where radiographs could be counted, and dental insurance claims data.

Results: Each four bitewing radiographic procedure was estimated to expose individual patients to 4.2 individual films. Root canal therapy, which was estimated to exposure patients to 3.5 to 4.8 periapical radiographs, showed large differences between exposed, recorded, stored and billed radiographs. For example, for a three canal root canal procedure, a dentist would expose 4.1 periapical x-rays, record 2.3, store 2.7 and bill for 0.60 of these films.

Conclusions: Under-reporting of dental radiographs commonly occurs in the dental chart compared with dentist surveys, although the magnitude of the under-reporting depends upon the type of associated procedure. We provide estimates for the true number of radiographs exposed for common dental procedures.

Introduction

Obtaining the most accurate information about health care utilization is important for clinicians, researchers and policy analysts. In epidemiological research, specific aspects of this utilization are often critical exposure or outcome variables. Various methods to measure utilization in the clinical setting are available, ranging from direct observation to claims data, to patient interview (76), although the chart or health care record has commonly been used in the past (see figure 3.1). Concerns have arisen, however, about the accuracy and completeness of these records for the reporting of clinical activities (77). For example, studies using direct observation as the reference standard have shown that both the medical record and claims data can substantially under-report clinical activity that occurs at provider-patient encounters; this under-reporting varies by the type of service (76). Recording of specific radiographic services, such as mammography, in the medical record show lower levels of sensitivity (0.62) and high levels of specificity (0.99) compared to direct observation, meaning that some procedures are not recorded, but procedures not done are rarely falsely recorded (76).

No parallel work has been published in dental practice, but a 1984 study showed that only 19% of 316 randomly sampled dental records were free of deficiencies in documentation under the sections of demographic data, medical history, radiographic exam, intraoral exam treatment plan and progress notes (78). No specific study of records for radiographs was mentioned, although stored radiographs were often found to be missing from charts (78). When dentists are asked how their own dental records correspond to published standards, they overestimate the completeness of these recordings (79). No previous studies have investigated the relationship between the actual number of dental radiographs exposed on patients, compared to the dental record, or procedures billed. A recent study compared the number of radiographic procedures billed, compared to those recorded, and found that 92.7% were recorded (80). A study comparing patient recall of dental radiographs with the dental chart, however, did raise multiple concerns about using the dental chart as the reference standard (81). The concerns consisted of dentists not recording discounted or free dental radiographic services, providing incomplete charts, or possibly under-counting radiographs due to medico-legal concerns.

Dental radiographs are invariably retaken because of procedural or processing errors (82). These films are rarely billed or recorded, and usually discarded, although little work outside dental schools or the military have been conducted (82;83;84). The rates of these retakes have also not been investigated in private practice, and any retakes would be expected to elevate the total films exposed, compared to billed, recorded and possibly stored films.

Various methods could be utilized to ascertain how well the dental record documents dental radiographic services performed, and to find the true number of radiographs exposed on patients. Direct observation, as used in studies of physician services, could be done, but such efforts are expensive and time consuming, and the presence of observers may alter the usual behavior of dentists and their staff. Less costly alternatives to direct observation are directly examining dental charts, since radiography usually leaves a physical trace – the radiograph – in the chart. The type and number of radiographs in the dental chart could be counted, and the written record abstracted. In addition, billing data could be scrutinized if most radiographs are charged as a separate fee. Another alternative includes asking dentists and their staff the number and type of radiographs they usually expose in specific clinical situations, although these estimates would depend upon accurate recall and would only depict the average number of films. We hypothesize that not all dental radiographs that are exposed are recorded, stored or billed, and that the discrepancies are largest for radiographs that are subsumed under the fee for related procedures.

Thus, the overall aim of this study was to estimate the true number of radiographs exposed on dental patients in private general dental practice for common dental procedures, and also the fraction that recorded, stored and billed data provide of this total exposure.

Methods

Overall Strategy

Because we needed to know the number of dental radiographs actually exposed in dental practice for a study comparing patient self report of dental radiographs with the dental record, and it was not feasible to directly observe dental radiography in private dental practice, we used an alternative method to estimate the total radiographs exposed on subjects. The overall strategy was to use to our advantage that most dental radiographs are taken to provide information so that a procedure can be performed, such as a dental restoration, extraction, root canal or prophylaxis. Radiographs are usually associated with these procedures. In addition, radiographs taken are stored in the dental record, so physical evidence is available to also measure the activity. Thus, we used multiple sources of information from different populations: surveys of dentists and their staff; insurance claims data; and actual dental charts with radiographs to estimate the exposed, recorded, stored and billed number and type of dental radiographs.

This strategy consisted of the following steps. First, we developed a flow sheet and model of dental radiographic utilization, and how exposed radiographs may be associated with recorded, stored and billed films. Next, using insurance claims data, we calculated the rates of dental radiographic procedures. Then, we obtained information about these different phases of dental radiography from multiple unrelated data sources: two surveys of dentists and staff; dental insurance claims; actual dental charts with radiographs, with and without billing records. These various sources from different populations provided information about specific but differing aspects of the radiographic process. For example, the number of billed radiographs could be ascertained from claims data, the number of recorded and stored films from in-office abstractions of charts, and exposed, recorded, stored and billed were gleaned from dentist surveys. The number of films usually exposed for specific procedures are reported by the dentists and their staff was used as the reference standard. Then, dental procedures commonly requiring radiographs on the same visit or just before, such as dental extractions, were investigated, and the numbers of radiographs exposed, recorded, stored and billed estimated, using the same method. Finally, numbers of radiographs usually exposed for various procedures were determined, as was the fraction that that records and billing data are of the total exposure.

Data and population sources

Table 3.1 shows the information sources used for estimating the different phases of dental radiography. First, in-person interviews with a convenience sample of dentist's (n=20) helped to gain in-depth information about the entire radiographic process. This survey, which was in tabular format, asked questions regarding the type and number of x-rays taken for 10 to 20 different dental procedures and whether those x-rays are recorded in treatment notes, stored in the patient chart and billed to the insurance to the insurance and/or patient (see Appendix A.3). Because this detailed table was a complex task, usually requiring explanation, it was not included in the later mail surveys. Second, a predominately mail survey of general dentists (n=100), hygienist (n=100) and assistants (n=100) was conducted in King County, Washington, where subjects were asked about their normal dental x-ray practices and usual numbers of radiographs that they retake. These subjects were selected from the business phone book, since this provides a near complete listing of all practicing dentists. Every twentieth general dentist listed in the phone book was included in this sample. The second part of the sample (n=90) consisted of dentists who had supplied dental records for a case-control study investigating looking at risk factors for intracranial meningioma (benign brain tumors). Over 90% of the surveys were conducted by mail, while the initial survey was administered via telephone or in-person interview, with investigator present for questions.

For the mailed surveys, a cover letter accompanied the questionnaire inviting the doctor and up to two other staff members with the most clinical experience to fill out the forms. Three weeks following the initial mailing, subjects on our mailing list received a letter thanking them if they had already filled out and sent in the survey and asking them to consider filling out and sending in the survey if they had not yet done so. No monetary reimbursement was offered to any subject. Survey subjects were asked to answer whether or not they perform full mouth x-rays (FMX), bitewing x-rays (BWX), panoramic (PANO) or cephalometric (CEPH) x-rays in their office. In addition, for the intraoral radiographs (FMX and BWX), subjects were asked to detail how many x-rays and what type (bitewing or periapical) comprised a set. For each type of x-ray taken in their office, subjects were then asked to recall the number of individual x-rays that typically might need to be retaken for any reason. Dentists were asked to estimate if their retake rates were more, less or the same as ten and twenty years ago. The surveys were reviewed and approved by the University of Washington Human Subjects Review Committee.

Subjects in the meningioma risk factor study gave their informed consent to allow us to contact their previous dentists. A subset of intact dental records from the meningioma validation study were abstracted either in-office or abstracted off site and returned to the dental office. The dental and radiographic procedures recorded in the chart were abstracted, and the types and numbers of dental radiographs were separately recorded. For a subset of these records (12/40), we also had claims data from Washington Dental Service, which will be described next.

The dental insurance claims came from the Washington Dental Service (WDS) data warehouse project, which is a computerized relational database of all WDS dental claims submitted since 1992. Washington Dental Service is a Delta Dental Plan third-party insurer and is the largest dental insurance carrier in the state of Washington. It provides for dental services to more than 1 million consumers through more than 2,000 providers in the state. Over 30% of the state population of over 5 million people receives dental care through this carrier, and 30% of our meningioma research subjects (181/600) were also found to have had dental care at some point during the time period from January 1,1993 to their interview date in 1996 to 2001. The database included the date, quantity and type of procedures performed along with the name and address of the treating dentist. Data queries were made using the subject's last name, first name initial and birth date. Duplicate treatment entries were checked for all retrieved data.

Step 1 – Construction of flow sheet of dental radiographic activity and hypothetical model.

We used in-person interviews and the first author's general dental experience to construct a flow sheet of decision processes and action for all phases of dental radiographic activity. From this, we developed an overall hypothetical model of dental radiography.

Step 2 – Determine the rates of common dental radiographs taken in dental practice.

We used the WDS claims data that was retrieved for 181 subjects in the meningioma risk factor study to determine the most common dental radiographic procedures taken in dental practice from 1992-2002. The rates of these services were calculated by including only those people with at least one dental procedure in the denominator, since it is difficult to ascertain all subjects with insurance but did not seek care. We also calculated the rates of the combinations of dental radiographs that are taken at any single dental visit. This analysis allowed us to know which radiographic procedures to concentrate, and which discrepancies between exposed and billed radiographs would create the greatest errors on a population basis.

Step 3a Use all data sources to estimate the exposed, recorded, stored and billed for common dental radiographic procedures.

The mean number and standard deviation of dental radiographs exposed, recorded, stored and billed was calculated for specific corresponding cells of the total exposure-recorded-stored-billed matrix. This was done for four bitewing, complete series (full mouth), one periapical and one panoramic radiographs. Some cells are exact numbers, since they are these quantities by definition. For example, four bitewing radiographs are equal to the billing procedure code of 0274, or bitewing radiographs – four.

Step 3b Use all data sources to estimate the exposed, recorded, stored and billed for dental procedures associated with radiographs taken on the same visit .

We determined the most common dental procedures associated with other dental radiographs, and focused on the ones in which under-reporting occurs. These included all root canal therapy, cast and prefabricated post and cores, and the evaluation of painful tooth.

Step 3c – Search for other dental procedures where films may be exposed uncommonly recorded, stored or billed.

In some instances, radiographs are exposed but not recorded, stored or billed, and these occurrences are not easily identified. Through the interviews and clinical experience, we created a table of dental procedures where radiographs may be exposed but rarely recorded, stored or billed. We also searched the WDS data for these and other procedures that are associated with any type of dental radiograph on the same visit to find hints of occasional billing.

Statistical Analysis

Rates of the number of procedures per person-year of dental treatment were calculated. We also calculated the means and standard deviations of radiographs using Excel 2000 (Microsoft Corp, Redmond, WA). Rates of retakes from surveys were converted to correspond to the fraction of additional films taken for one procedure. Potential factors that could affect the relationship between exposed and recorded, or billed radiographs included the subject's age, gender and number of existing teeth, the dentist's specialty, years of care, whether they had dental insurance or not, and the region. We partially controlled for these covariates in step 3 by restricting the sample to adults, people with at least 14 teeth, general dentists, and 1992-2002 years of dental care. One hundred percent of the WDS sample had dental insurance, while an estimated 50 to 60% of the meningioma subjects had dental insurance. Proportions and percentages of the total exposed radiographs were calculated. An average of all exposed, recorded, stored and billed cells was computed.

Results

Flowsheet and hypothetical model construction. The response rate for the in-person interview was 95% (24 of 25 subjects approached), and average age of the dentists was 42.2, and the dentists had been in practice for 16.9 years. Figure 3.2

is a flow diagram of the common actions and decisions in exposing, developing, billing, reading, recording and storing a dental radiograph for a modern day, computer based dental practice. This diagram illustrates that retakes of radiographs occur early in the process and are rarely captured with billing, records or stored radiographs. It also shows that any radiograph may be stored, but not billed or recorded, recorded but not billed or stored; and billed but not stored or recorded, any other combination of these three conditions. However, the exposed films are always greater than those that are recorded, recorded, stored or billed. Stored radiographs are expected to diminish over time as films are lost with use, sent to other locations or purged after time periods usually determined by the dentist. Figure 3.3 shows a hypothetical model of dental radiographic exposure patterned after figure 3.2. Insurance records allow estimation of billed radiographs, examination of the actual dental chart allows determination of the number of stored radiographs, abstraction of the chart allows the recorded number of radiographs to be known, and a dentist and dental staff survey gives and estimate of the usual number of films exposed for specific dental procedures.

<u>Determine the rates of common dental radiographs taken in dental practice.</u>

Table 3.2a shows the rates of common dental radiographic procedures from a 44% sample of 181 meningioma research subjects who had 3,915 different dental procedures performed from 1992-2002, with an average of 3.7 years of treatment follow up. Four bitewing radiographs are the most common, with a rate of over 53 per 100 person years for those subjects with at least one dental visit. Table

3.2b shows the rates of dental radiographic visits, in which multiple combinations of radiographic types are now commonly encountered. The four bitewing radiograph visit is also the most common, followed by one periapical radiograph, followed next by four bitewings and two periapical radiographs.

Use all data sources to estimate the exposed, recorded, stored and billed for common dental radiographic procedures.

The response rate for the mailed survey of dentists was 62% (96/155), and their average age was 41.2. The response rate for the mailed survey of dental assistants and hygienists was 55% (172/310), although not all offices employ hygienists, so this may be an underestimate. Their average age of the combined dental staff was 38.4. Table 3.3a shows the exposed, recorded, stored and billed numbers of bitewing radiographs for the 4 bitewing radiograph procedure. The mean numbers of radiographs was 4.2, reflecting the 6 per 100 individual bitewing retake rate reported by the dentists and staff. Billed/exposed ratios were 95%. Full mouth radiographs had a mean number of 19.5 periapical/bitewing radiographs exposed, 17.9 recorded, 17.9 stored and 17.8 billed (table 3.3b). We had only minimal data available to determine 1 periapical radiographs, so these data are not shown. Panoramic radiographs showed the highest estimated retake rates of about 10 per 100 films, and the number of exposed panoramic films was 1.11, recorded was 1.0, stored 1.0, and billed 1.0.

<u>Use all data sources to estimate the exposed, recorded, stored and billed for dental procedures associated with radiographs taken on the same visit .</u>

The mean number of periapical radiographs reportedly exposed from dentist surveys for 1 through 4 canal root canals was 3.2, 3.5., 4.1, 4.2, respectively, while the number billed was 0.5, 0.8, 0.6, 1.0, respectively. All types of root canal therapy showed large discrepancies between the exposed and billed films, with billed/exposed percentages of 6 to 34%. Post and core restorations also showed both periapical and some bitewing radiographs only exposed but not billed. Table 3.4e has estimations for post and core procedures, which also showed both periapical and some bitewing radiographs only exposed and not billed. Table 3.4f, which shows estimations for a visit to evaluate an acutely painful tooth, showed that most exposed films are billed.

<u>Search for other dental procedures where films may be exposed uncommonly recorded, stored or billed.</u>

Table 3.5 lists other dental procedures where films may be exposed but rarely recorded, stored or billed, in the approximate order of occurrence, based on dentist interviews, clinical experience, and some data from WDS. Additional periapical radiographs during after tooth extractions were likely the most common instances of exposed but not recorded, stored or billed films, down to dental board examinations, which are infrequent on a population basis but individuals have been shown to be exposed to many films(85).

Discussion

This study shows that dental radiographs are variably recorded, billed and stored, although most separate dental radiographic procedures showed relatively little discrepancy (5 to 10%) between the dentist estimated exposed and recorded, stored and billed radiographs. These minimal discrepancies likely reflect the influence of dental insurance in the United States, where dental radiography is designated a diagnostic service and most insurance plans reimburse patients at high percentage rates of 70 to 100% (Michael del Aguilar PhD, personal communication; Washington Dental Service, Uniform Medical Program, 2001-2004). Root canal therapy, on the other hand, showed large differences between exposed, recorded, stored and billed films, probably because radiographs are usually included in the overall fee for the root canal procedure, and some insurance plans have restrictions on the number of separate periapical radiographs that can be billed. If we investigated other dental procedures that have not commonly been reimbursed by dental insurance, such as oral hygiene instructions, the recorded and billed proportions would likely be in the range of 2 to 5%, for adults.

Some of the limitations of this study are small sample sizes for some of the surveys and information sources, which likely resulted in unstable mean values. However, the small standard deviations for many of the cells show that there are minimal differences in clinical practices for many of these procedures. We also depended upon the self report of radiography for exposed films, and the dentists may not have been accurate in their estimates, although there was surprising uniformity in many of the answers. Another limitation is that we cannot ascertain every time a dentist takes a radiograph but does not record or bill for it. But, by investigating claims data and dental charts, we have shown that whatever films may be taken on and off, they must be small in number.

Some of the strengths of this analysis should be noted. This study fills a large void where no similar work appears to have been conducted. We also did not rely solely on self-report, and data from multiple sources helped to bolster confidence that the number of films usually exposed, recorded, stored and billed are accurately reflected in these estimates.

Since our sample was based partly on an insured population in mainly urban and suburban counties, the generalizability of these estimates to other populations is likely limited. People without dental insurance utilize dental care less often, and when they do, they would likely put pressure on dentists to also restrict radiographic practices. We hypothesize that this may result in fewer billed radiographs, and that radiographs are more likely to be included in other dental procedure fees if a patient must may for the services completely out of pocket.

These estimates may only apply for present day practice in similar settings in the Pacific Northwest of the US. Differences for past practices are likely, especially for the time before dental insurance. Dental articles from 60 to 80 years ago frequently discussed how dentists should charge for radiographs, and not use them as a method mainly to find more dental pathology (86). In one early survey from 1962, ~80% of dentists said that they charged for dental x-rays (87). We also found evidence from dental records collected before 1970 that showed radiographs exposed but not charged to the patient, and instead included in a fee for immediate dentures.

In summary, we have demonstrated how the true exposure to dental radiography for common dental procedures can be estimated by using multiple information sources. Although the dental record can be used for some radiographic procedures, such as four bitewing radiographs, the record will underestimate films exposed for root canal therapy. Billed procedures will generally underestimate root canal films to the greatest extent. As we hypothesized, radiographs that are included in the overall fee for a procedure are generally under-billed and recorded.

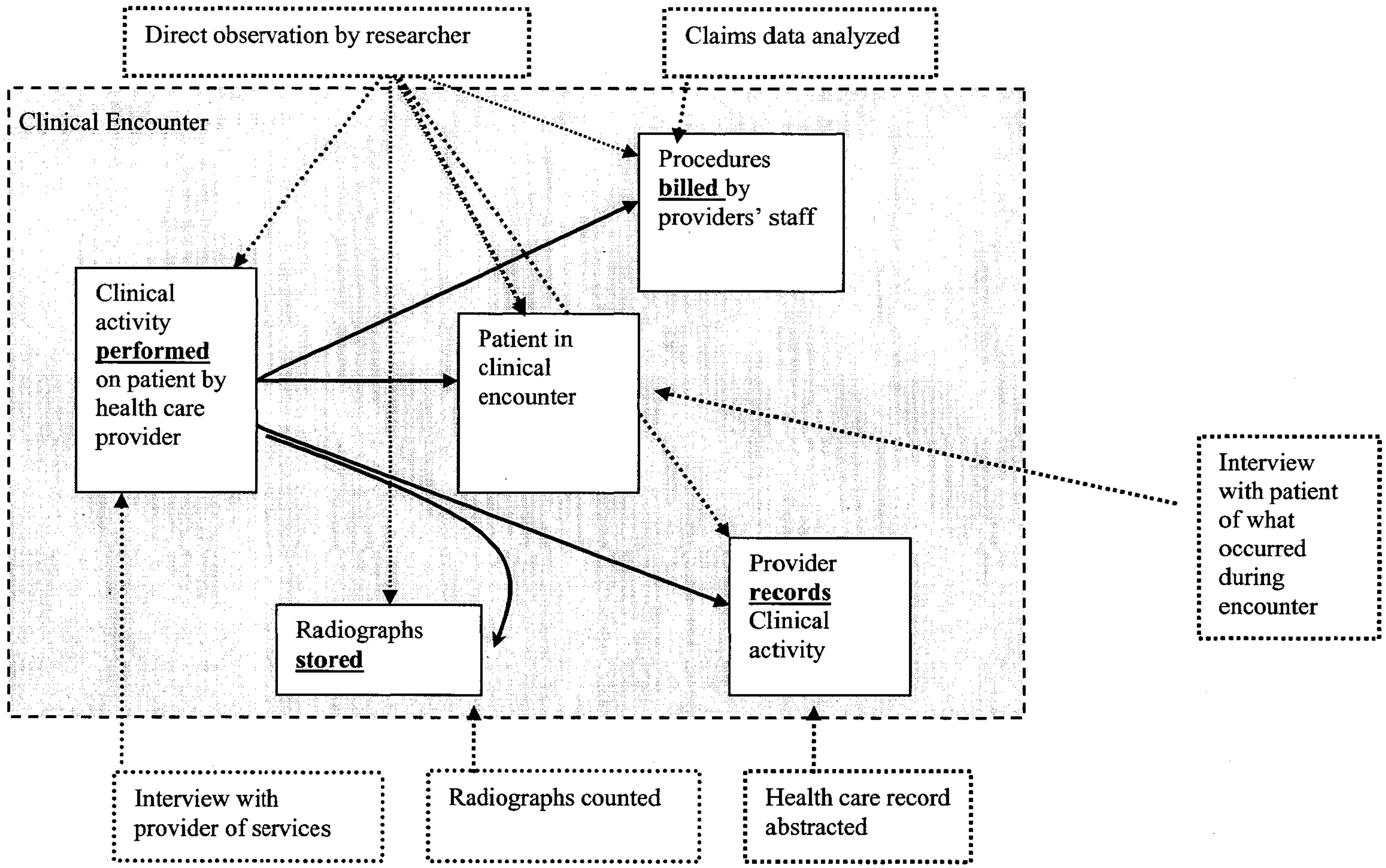
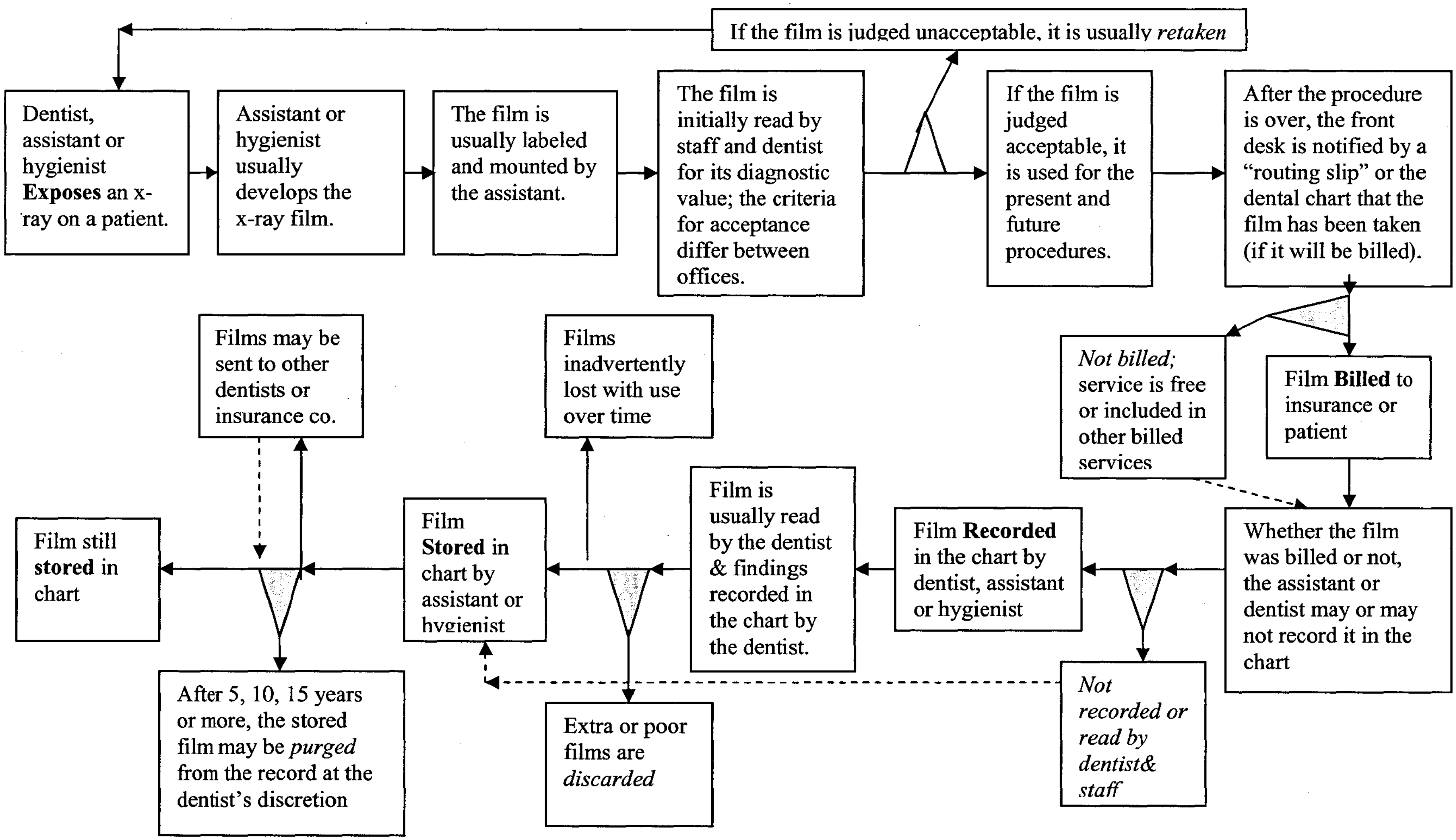


Figure 3.1 Research methods available to measure health care activities. Clinical activity can be directly observed (which is usually the reference standard), claims data analyzed, patient interviewed, record abstracted, provider interviewed, or, in the case of radiography, films counted.

Figure 3.2 Overall flow sheet of decision processes for exposing, billing, recording and storing dental radiographs in present day private dental practice.

This schematic diagram shows the flow of clinical activity and decision processes for exposing, billing, recording and storing dental radiograph in present-day private dental practice in US. The triangles denote decision nodes. Radiographs are generally taken by assistants or hygienists, and developed/ mounted by them. After a cursory review, the decision is made to either use the film or to retake it if it is deemed inadequate. Usually a routing slip of the procedures performed is sent to the front desk for billing if a computer system is used. If the radiograph is part of another procedure, or it is decided that it will not be charged, it is not placed on the routing form, and it is not billed. The staff then documents the x-ray in the dental chart. The dentist usually reads the x-ray after the procedure and records the diagnosis in the chart. Films used for a specific procedure like endodontics may be discarded, especially if they were rapidly processed, or other films that have technical or processing errors. The films are then stored in the dental chart. Films may be taken out of the chart/record for various reasons: if they are sent to another treating dentist or specialist, or they may be purged after the legal time limit (5 years in Washington State). Note that not all exposed films are recorded or billed, and stored radiographs may be taken from the chart, an event that increases with elapsed time. As the diagram shows, retaken x-rays are rarely recorded, billed or stored. The flow sheet differs for the pre-computer and insurance years, which were generally before 1965. During this time period, dentists usually took the films and recorded them onto a 4 x 7 inch card from which billing was determined. Thus, the numbers of recorded and billed x-rays in this time period were usually identical.


If the film is judged unacceptable, it is usually retaken
Dentist, assistant or hygienist Exposes an x-ray on a patient.
Assistant or hygienist usually develops the x-ray film.
The film is usually labeled and mounted by the assistant.
The film is initially read by staff and dentist for its diagnostic value; the criteria for acceptance differ between offices.
If the film is judged acceptable, it is used for the present and future procedures.
After the procedure is over, the front desk is notified by a "routing slip" or the dental chart that the film has been taken (if it will be billed).
Not billed; service is free or included in other billed services
Film Billed to insurance or patient
Whether the film was billed or not, the assistant or dentist may or may not record it in the chart
Not recorded or read by dentist& staff
Film Recorded in the chart by dentist, assistant or hygienist
Film is usually read by the dentist & findings recorded in the chart by the dentist.
Films inadvertently lost with use over time
Extra or poor films are discarded
Film Stored in chart by assistant or hygienist
Films may be sent to other dentists or insurance co.
After 5, 10, 15 years or more, the stored film may be purged from the record at the dentist's discretion
Film still stored in chart

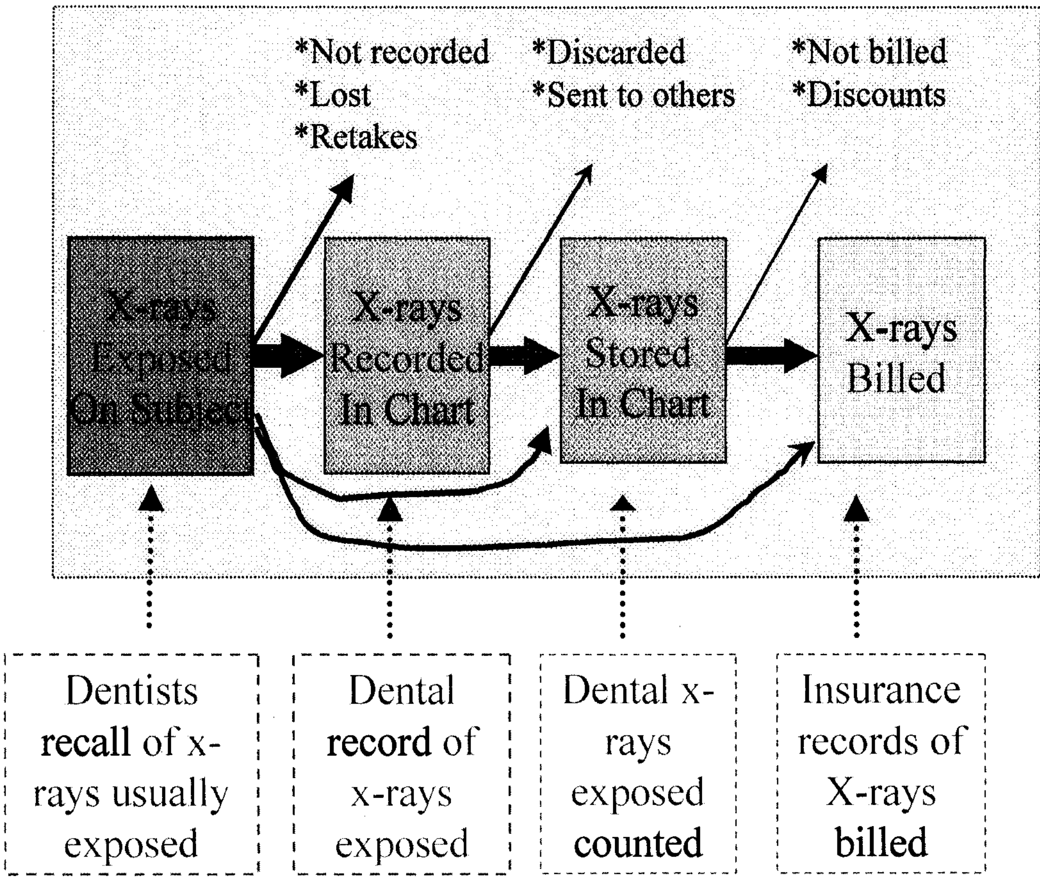


Figure 3.3 Hypothetical model of dental radiographic exposure, recording, storage and billing.

Dental radiographs exposed on patients are not easily known unless all clinical activity is directly observed. A secondary approach is to measure recorded, stored and billed x-rays for common dental procedures and reconstruct the films likely exposed. Such an approach is supplemented by dental providers' recall of the number of films usually exposed for specific dental procedures.

Table 3.1 Description of information sources used to assess different phases of dental radiography.

	Information source	Sample description	Counties in Washington state	# dental Records/ surveys Sought	# dental Records/ surveys Received	Dental radiographs Exposed	Recorded	Stored	Billed
1	In-person interviews with dentists	Convenience sample	King and Pierce	25	24				
2	Mailed dentist survey of usual x-ray practices	50% survey sample of subjects, 50% meningioma cases and controls	King, Pierce, Snohomish	155	96		----	----	
3	Mailed dental assistant /hygienist survey of usual x-ray practices	50% survey sample of subjects, 50% Meningioma cases and controls	King, Pierce, Snohomish	310	172		----	----	
4	Actual dental chart records + radiographs in chart + billing information.	Meningioma study cases & controls	King, Pierce, Snohomish	19	12	---			
5	Actual dental chart records + stored radiographs in chart	Meningioma study cases & controls	King, Pierce, Snohomish	35	28	---			---
6	Washington Dental Service insurance claims	Meningioma study cases & controls	King, Pierce, Snohomish	181	181	---	---	---	

Legend:
[shaded box] "- denotes cell where information is available from source"

Table 3.2A Rates of billed dental radiographic procedures in western Washington state, 1992-2002.

	Radiographic Procedure	Common Abbrev.	ADA Code**	Rates of Types of Dental Radiographic Procedures* number of Procedures***	Rate of radiographic procedures per 100 person-years	One film every *X* years
1	Bitewings- Four films	4 BW	274	333	54.8	1.8
2	Periapical- One Film	1 PA	220	242	39.8	2.5
3	Periapical- Additional Film	1 PA ADD	230	98	16.1	6.2
4	Complete Series of Films (Full Mouth)	FMX	210	48	7.9	12.7
5	Bitewings- Two films	2 BW	272	47	7.7	12.9
6	Panoramic Film	PANO	330	41	6.7	14.8
7	Vertical BW -7 to 8 films	7 VERT BW	277	9	1.5	68
8	Bitewing- single film	1 BW	270	8	1.3	76
9	Bitewing - three films	3 BW	273	3	0.5	203
10	Cephalometric film	CEPH	340	1	0.2	608

Legend:

* Rates calculated using 3.8 mean years of treatment for subjects with at least one dental procedure during their coverage.
160 total subjects with any type of dental treatment were included

** American Dental Association 5 digit procedure codes

*** 44% sample of WDS claims data

Table 3.2B Rates of dental radiographic procedures during a single visit in western Washington state, 1992- 2002.

	Radiographic Procedure	Common Abbreviation.	Total Number of procedures	Radiographic procedures per 100 person-years	One set of films every *X* years
1	Bitewings- Four films	4 BW	169	56.3	1.8
2	Periapical- One Film	1 PA	78	26	3.8
3	4 Bitewings + Two Periapicals	4 BW + 2 PA	29	9.7	10.4
4	Complete Series of films	FMX	27	9	11.1
5	Two Periapical films	1 PA + 1 PA	15	5	20
6	Two Bitewing films	2 BW	15	5	20
7	Two Bitewing + Two Periapical Films	2 BW + 2PA	14	4.7	21.4
8	Four Bitewing + One Periapical Film	4 BW + 1 PA	13	4.3	23.1
9	Panoramic Film	PANO	12	4	25
10	Four Bitewing + One Panoramic Film	4 BW + PANO	8	2.7	37.5
11	Seven Vertical Bitewing Films	7 VERT BW	5	1.7	60
12	One Bitewing Film	1 BW	3	1	100.1
13	Seven Vertical Bitewing + One Panoramic Films	7 BW + PANO	3	1	100.1
14	Four Bitewing + One Panoramic and Two Periapical Films	4 BW + PANO + 2 PA	2	0.7	150.1
15	Two Bitewing + One Periapical Film	2 BW + 1 PA	2	0.7	150.1
16	One Cephalometric Film	1 CEPH	1	0.3	300.2
17	Two Bitewing + Two Periapical + One Panoramic Films	2 BW + 2 PA + PANO	1	0.3	300.2
18	Four Bitewing + Two Bitewing + Two Periapical Films	4 BW + 2 BW + 2 PA	1	0.3	300.2
19	One Panoramic + One Periapical Film	PANO + PA	1	0.3	300.2
20	Three Bitewing Films	3 BW	1	0.3	300.2
21	One Bitewing + One Periapical Film	1 BW + 1 PA	1	0.3	300.2

Legend:

Rates calculated using 3.8 mean years of treatment

181 total subjects with any type of dental treatment were included

* American Dental Association 5 digit procedure codes

** 44% sample of WDS claims data

Table 3.3A. Estimation of four bitewing exposed, recorded, stored and billed radiographs.

Information source	no. dental records/ sources	total 4 BW procedures	Dental bitewing radiographs: Exposed mean	Exposed s.d.	Recorded** mean	Recorded** s.d.	Stored mean	Stored s.d.	Billed*** mean	Billed*** s.d.	stored/ exposed ratio	recorded/ exposed ratio	billed/ exposed ratio
In-person interviews with dentists of entire process**	24	na	4.11	---	4.0	0.0	4.0	0.0	4.0	0.0	97%	97%	97%
Mail survey of dentists *	96	na	4.26	---	----		----		4.0	0.0			94%
Mailed survey of dental assistant/hygienists *	172	na	4.20	---	----		----		4.0	0.0			95%
Actual dental chart records + stored radiographs	28		---	---	4.0		3.9		---	---			
Actual records + radiographs + billing information	12	33	---		4.0	0.0	3.8	0.9	3.6	1.5			
Washington Dental Service insurance claims*	181	333	---	---	---	---	---	---	4.0	0.0	***		
unweighted average - records only			**na**		**4.0**		**3.9**		**3.8**				
unweighted average - surveys only			**4.2**		**4.0**		**4.0**		**4.0**		**95%**	**95%**	**95%**
survey - record differences			**na**		**0.0**		**0.2**		**0.2**				
survey - record percent differences					**100%**		**96%**		**95%**				

Legend:

* For years 1992-2002

** Some recorded entries were illegible and all treatment was excluded

*** By definition, billed 4 bitewing procedures equal 4.0 films billed

Table 3.3B. Estimation of full mouth series exposed, recorded, stored and billed radiographs.

Information source	no. dental records/ sources	total FMX procedures	Complete series - Full mouth: Dental periapical and bitewing radiographs								stored/ exposed ratio	recorded/ exposed ratio	billed/ exposed ratio
			Exposed		Recorded**		Stored		Billed***				
			mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.			
In-person interviews with dentists of entire process	24	na	20.3		17.9		17.9		17.9		88%	88%	88%
Mail survey of dentists *	96	na	**19.2**		---		---		**17.6**				92%
Mailed survey of dental assistant/hygienists *	172	na	**19.0**		---		---		**17.8**				94%
Actual dental chart records + stored radiographs	28		---		**		14.8		***				
Actual records + radiographs + billing information	12	2	---		**		17.0		***				
Washington Dental Service insurance claims*	180	48	---		---		---		---		***		
unweighted average - records only			**na**		–		**15.9**		***				
unweighted average - surveys only			**19.5**		**17.9**		**17.9**		**17.8**		**92%**	**92%**	**91%**
survey - record differences			**na**		—		**2.0**		—				
survey - record percent differences					—		**89%**		—				

Legend

* For years 1992-2002

** Complete series listed by abbreviation in chart with no listing of number of films

*** No information on number of radiographs billed by definition; only lists that a complete series was taken, which is defined as over 10 individual films.

Table 3.3C. Estimation of panoramic exposed, recorded, stored and billed radiographs.

Information source	no. dental records/ sources	total 1 PANO procedures	Panoramic radiographs: Exposed mean	Exposed s.d.	Recorded** mean	Recorded** s.d.	Stored mean	Stored s.d.	Billed*** mean	Billed*** s.d.	stored/ exposed ratio	recorded/ exposed ratio	billed/ exposed ratio
In-person interviews with dentists of entire process	24	na	1.15		1.0		1.0		1.0		87%	87%	87%
Mail survey of dentists *	96	na	1.10		---		---		1.0				91%
Mailed survey of dental assistant/hygienists *	172	na	1.08		---		---		1.0				93%
Actual dental chart records + stored radiographs	28		---		0.80		1		1				
Actual records + radiographs + billing information	12		---		1.0		0.9		1.0				
Washington Dental Service insurance claims*	181		---		---		---		1.0				
unweighted average - records only			**na**		**–**		**0.95**		**1.00**				
unweighted average - surveys only			**1.11**		**1.00**		**1.00**		**1.00**		**90%**	**90%**	**90%**
survey - record differences			**na**		**----**		**0.05**		**0.00**				
survey - record percent differences							**95%**		**100%**				

Legend

* For years 1992-2002

Table 3.4A. Estimation of one canal root canal exposed, recorded, stored and billed radiographs.

Information source	no. dental records or sources	total 1 canal RCT procedures	Periapical radiographs: Exposed mean	Exposed s.d.	Recorded** mean	Recorded** s.d.	Stored mean	Stored s.d.	Billed mean	Billed s.d.	stored/ exposed ratio	recorded/ exposed ratio	billed/ exposed ratio
In-person interviews with dentists of entire process	24	na	3.3	0.80	3.0	1.2	3.2	0.9	1.1	1.1	97%	91%	33%
Mail survey of dentists *	24	na	2.9	1.2	----		----						
Mail survey of endodontists	19	na	3.40	0.50									
Mailed survey of dental assistant/hygienists *	119	na	—	—	----	----	----	---	—	—			
Actual dental chart + stored radiographs	28	?	---	---	1.2		2.7		---	---			
Actual chart + radiographs + billing information	12	6	---		1.0		3.0		0.5				
Washington Dental Service insurance claims*	181	13	---	---	---	---	---	---	0.4	0.6			
unweighted average - records only			**—**		**1.1**		**2.9**		**0.5**				
unweighted average - surveys only			**3.2**		**3.0**		**3.2**		**1.1**		**100%**	**94%**	**34%**
survey - record differences- absolute			---		**1.9**		**0.4**		**0.7**				
survey - record differences - percent			---		**37%**		**89%**		**41%**				

Legend

* For years 1992-2002

Table 3.4B. Estimation of two canal root canal exposed, recorded, stored and billed radiographs.

Information source	no. dental records or sources	total 2 canal RCT procedures	Periapical radiographs: Exposed mean	Exposed s.d.	Recorded mean	Recorded s.d.	Stored mean	Stored s.d.	Billed mean	Billed s.d.	stored/ exposed ratio	recorded/ exposed ratio	billed/ exposed ratio
In-person interviews with dentists of entire process	24	na	3.5	0.80	3.3	1.3	3.0	0.9	0.6	0.8	86%	94%	17%
Mail survey of dentists *	19	na	3.50	0.60	----		----						
Mailed survey of dental assistant/hygienists *	119	na			----		----						
Actual dental chart records + stored radiographs	28		---	---	0.8		2.1		---	---			
Actual records + radiographs + billing information	12		---		0.6		3.6		0.6				
Washington Dental Service insurance claims*	181		---	---	---	---	---	---	1.0	0.6			
unweighted average - records only		**0**	**---**		**0.7**		**2.9**		**0.8**				
unweighted average - surveys only		**na**	**3.5**		**3.3**		**3.0**		**0.6**		**86%**	**94%**	**17%**
survey - record differences- absolute			---		**2.6**		**0.2**		**-0.2**				
survey - record differences - percent			---		**21%**		**95%**		**133%**				

Legend

* For years 1992-2002

Table 3.4C. Estimation of three canal root canal exposed, recorded, stored and billed radiographs.

Information source	no. dental records or sources	no. 3 canal root canal procedures	Periapical radiographs: Exposed mean	Exposed s.d.	Recorded mean	Recorded s.d.	Stored mean	Stored s.d.	Billed mean	Billed s.d.	stored/ exposed ratio	recorded/ exposed ratio	billed/ exposed ratio
In-person interviews with dentists of entire process	24	na	4.6	0.7	3.5	1.4	4.0	0.9	0.8	0.9	87%	76%	16%
Mail survey of dentists *	19	na	3.5	0.6	----		----						
Mailed survey of dental assistant/hygienists *	119	na	--	---	----		----		---	---			
Actual dental chart records + stored radiographs	28	23	---	---	0.7		2.6		---	---			
Actual records + radiographs + billing information	12	14	---		0.5	0.7	4.1	1.1	0.5	0.6			
Washington Dental Service insurance claims*	180	13	---	---	---	---	---	---	0.7	0.5			
unweighted average - records only		**50**	**—**		**0.6**		**3.4**		**0.6**				
unweighted average - surveys only		**na**	**4.1**		**3.5**		**4.0**		**0.8**		**99%**	**86%**	**18%**
survey - record differences- absolute			---		**2.9**		**0.7**		**0.2**				
survey - record differences - percent			---		**17%**		**84%**		**79%**				

Legend

* For years 1992-2002

Table 3.4D. Estimation of four canal root canal exposed, recorded, stored and billed radiographs.

Information source	no. dental records or sources	total 4 canal RCT procedures	Periapical radiographs								stored/ exposed ratio	recorded/ exposed ratio	billed/ exposed ratio
			Exposed		Recorded		Stored		Billed				
			mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.			
In-person interviews with dentists of entire process	24	na	4.8	1.0	3.9	1.7	3.9	1.0	0.3	0.7	81%	81%	6%
Mail survey of dentists *	19	na	3.5	0.6					---				
Mailed survey of dental assistant/hygienists *	119	na			---		---		---				
Actual dental chart records + stored radiographs	28	4			0.80		1		---				
Actual records + radiographs + billing information	12	0			---		----		---				
Washington Dental Service insurance claims*	181	1							*1.0*	*0.0*			
unweighted average - records only		**5**	—		**0.8**		**1.0**		**1.0**				
unweighted average - surveys only		**na**	**4.2**		**3.9**		**3.9**		**0.3**		**94%**	**94%**	**7%**
survey - record differences- absolute			---		**3.1**		**2.9**		**-0.7**				
survey - record differences - percent			---		**21%**		**26%**		**333%**				

Legend

* For years 1992-2002

Table 3.4E. Estimation of post-core restoration exposed, recorded, stored and billed radiographs.

Information source	no. dental records or sources	total post core procedures	Periapical radiographs Exposed PA	Exposed BW	Recorded PA	Recorded BW	Stored PA	Stored BW	Billed PA	Billed BW	stored/ exposed ratio	recorded/ exposed ratio	billed/ exposed ratio
In-person interviews with dentists of entire process	24	na	0.98	0.10	0.9	0.0	0.9	0.0	0.1	0.0	88%	95%	7%
Mail survey of dentists *	24	na	1.30	1.00	----		----						
Mailed survey of dental assistant/hygienists *	119	na	---	---	----		----						
Actual dental chart records + stored radiographs	28	12	---	---	0.2	0.1	1.0	0.2	---	---			
Actual records + radiographs + billing information	12	4	---		1.0	0.2	1.0	0.1	0.2				
Washington Dental Service insurance claims	180	8	---	---	---	---	---	---	0.0	0.0			
unweighted average - records only		**24**	**—**		**0.6**	**0.2**	**1.0**	**0.2**	**0.1**	**0.0**			
unweighted average - surveys only		**na**	**1.1**	**0.6**	**0.9**	**0.0**	**0.9**	**0.0**	**0.1**	**0.0**	**75%**	**82%**	**6%**
survey - record differences- absolute			---		**0.3**	**-0.2**	**-0.1**	**-0.2**	**0.0**	**0.0**			
survey - record differences - percent			---		**65%**		**116%**		**143%**				

Legend

* For years 1992-2002

Table 3.4F. Estimation of exposed, recorded, stored and billed radiographs to evaluate an acutely painful tooth.

Information source	no. dental records or sources	total evaluation of acute pain pro.	Periapical and bitewing radiographs: Exposed PA	Exposed BW	Recorded PA	Recorded BW	Stored PA	Stored BW	Billed** PA	Billed** BW		PA stored/ exposed ratio	PA recorded/ exposed ratio	PA billed/ exposed ratio
In-person interviews with dentists of entire process	24	na	1.15	0.20	1.1	0.1	1.1	0.0	1.1	0.0		96%	96%	96%
Mail survey of dentists *	0	na	---		---		---		---					
Mailed survey of dental assistant/hygienists *	119	na	---		---		---		---					
Actual dental chart records + stored radiographs	28				0.80	0.2	1.0	0.1	---	0.2				
Actual records + radiographs + billing information	12	2			1.0	0.4	0.5	0.2	1.0	0.1				
Washington Dental Service insurance claims***	181	55							*1.0*	*0.1*	**			
unweighted average - records only		**57**	—		**0.9**	**0.3**	**0.8**	**0.2**	**1.0**	**0.1**				
unweighted average - surveys only		**na**	**1.2**	**0.2**	**1.1**	**0.1**	**1.1**	**0.0**	**1.1**	**0.0**		**96%**	**96%**	**96%**
survey - record differences- absolute			---		**0.2**		**0.4**		**0.1**					
survey - record differences - percent			---		**82%**		**68%**		**91%**					

Legend

* For years 1992-2002

** Used Emergency Exam code for insurance claims

Table 3.5. Other dental procedures where radiographs may be exposed but rarely billed or recorded.

Estimated Rank Occurrence	Film type	Number of Films	Associated Procedure	Event	Any evidence from WDS data?	Any evidence from survey respondents?	From first author's clinical experience?
1	Periapical	1 to 2	Tooth extraction	During and after difficult tooth extractions	yes	yes	yes
2	Periapical	1	Tooth extraction	To evaluate post-operative pain after extraction	yes	yes	yes
3	Bitewing	1	Crown seat	After seating a crown to check on cement, margins	yes	yes	no
4	Bitewing	1 to 2	Pin restoration	To evaluate placement of pin retained core restorations	yes	yes	yes
5	Periapical	2	Emergency Exam	Impoverished patient with acute dental pain	no	no	yes
6	Any type	1 to 20	Any Dental	Films lost and taken within ~1 year or less	no	yes	yes
7	Vertical Bitewing	1 to 2	Root planing	After root planing/curettage to note if all calculus has been removed	yes	yes	no
8	Periapical	1	Crown seat	Films taken for administrative reasons (document need for crown)	no	yes	yes
9	Bitewing	1	Dental amalgams	After quadrant of dental amalgams placed	no	yes	no
10	Bitewing	1	Crown seat	Before or after seating a crown to check on margin	no	yes	no
11	Periapical	1 to 10	Dental implant	To check on placement of dental implant	no	yes	no
12	Panoramic	1	Any Dental	Dentist or staff relatives without dental insurance*	no	yes	yes
13	Full mouth	24	Any Dental Board	Dental board examination evaluation**	no	no	yes

Legend:
* - relatives without dental insurance would also likely have 4 bitewing and assorted periapical films taken also.
** -- dental board examination patients would also likely have 4 or more bitewings and assorted periapical films taken.

Chapter 4: Capture-recapture methods to determine lifetime dental providers.

Objectives: People in US typically see multiple dentists for dental care over their lifetime. Presently, no central database exists that lists all dental care and providers. Consequently, validation of self- reported lifetime dental care is difficult if the dentists visited are only known through self report, which is fallible. Capture-recapture methods have been developed to ascertain the total number of individuals in a population when multiple overlapping sources of information are available. The primary aim of this study was to estimate the total number of dentists seen over a lifetime, and to estimate the completeness of subject recall.

Methods: In a study of 200 subjects with benign intracranial meningiomas, and 400 age and gender-matched controls, subjects first reconstructed their lifetime dental care during an in-person interview using photos, props and a life events calendar. Two, two-source capture-recapture problems were constructed; one between subject recall and dental records gathered from practitioners for a subset of cases and controls, and the other between subject recall and insurance claims from a dental data warehouse. Since multiple, intersecting sources of dental care were available, capture-recapture methods were used to determine the proportion of dentists not recalled by the subjects in their original interviews, and the percent of dentists not recalled.

Results:

Using capture-recapture methods with insurance claims, subject recall of dentists for the years 1993 to 2001 was 86% complete among cases, and 74% complete among controls. A similar analysis for all years, using records and recall as sources, showed that cases recalled 82% of lifetime dentists, and controls, 85%, yielding a mean of 6.2 (95% C.I., 5.8 – 6.6) lifetime dentists for cases, and 6.5 (95% C.I. 6.1 – 6.9) for controls. When a subset of forgotten dentists and dental care were compared with recalled dentists, results showed that these forgotten providers were more likely to be dental specialists, were visited for a shorter amount of time, but proportionally more dental radiographs were taken at these visits.

Conclusions: Even with intensive interviewing, subjects forgot at least 15 to 18% of the dentists they had seen in their lifetime. Assessing the completeness of 'gold standards' of health care utilization in validation studies is recommended.

Introduction

Recall of distant or mundane exposures by research subjects is often required for epidemiological studies. Concerns exist about the accuracy of this information, and validation studies to check the accuracy have been conducted. When health care utilization is the exposure of interest, health care records are usually the reference standard for these validation studies (77). For some countries, such as Sweden, or within health maintenance organizations (HMO) in the US, the vast majority of medical care is provided within a health care system, so that most all of the medical visits will be listed in the medical record system (88). Dental care in the US, on the other hand, has not been provided by a single centralized practice until recently in some HMO's, and instead has been done by solo private practice dentists in separate offices. Even today, no central database of all dental care exists in the US, and tracking all of a subject's dentists and dental care over a lifetime must rely on the recall of a person. Recent health care validation studies have raised concerns about relying solely on a subject's recall to identify all health care providers (88). Since obtaining records is dependent upon the recall of a subject, someone with relatively poor recall may forget multiple health care providers, and, hence the validation reference standard that is constructed will be a serious underestimate of the actual number of providers, and of the health care provided. The only demonstrated method to work around this limitation is to study populations in which all health care is captured in a single record system, such as in an HMO or a centralized health care system, but even these studies have been shown to miss at least 20% of medical radiographic utilization done outside the system (89).

Capture-recapture methods may be able to overcome these obstacles of obtaining records of all health care provided, especially in the case of US dental care. The name of these methods comes from their early use in obtaining estimates of the total population of animals in the wild (90). For example, behavioral ecologists would capture a group of bears in the wild, tag them, and then let them loose to roam again. A few weeks later, after the animals had traveled and mixed in with other animals, they would recapture another set of bears, and then ascertain how many they had previously captured, and how many were newly captured. Using simple formulas, the number of animals never captured can be calculated, and hence the total population known (91). These same methods have been extended and expanded for use with humans to estimate population size when it is difficult to measure, such as with IV drug abusers, by using two or more sources or lists enumerating people with the condition (92). Because we needed to perform a validation study to ascertain lifetime dental care and dental radiography in a study of the risk factors for benign brain tumors, we proposed to use capture-recapture methods to estimate the total number of dental providers. Since we had several separate data sources of the dentists seen for care, we hoped to calculate the total number of dentists visited, so that the validation reference standard will be a complete list of all providers and potentially all the corresponding records. Thus, the primary aim of this study was to use capture-recapture methods to find the number of total lifetime dentists visited by subjects in a case-control study of benign brain tumors. The secondary aims were to describe how we attempted to enhance recall of lifetime dentists, to assess the completeness of recall of dentists, to verify if differences in completeness existed between cases and controls, young vs. old subjects, and recent vs. distant dental care. Finally, we estimated the number of dental radiographic visits likely missed if we relied only upon subject recall of lifetime dentists.

Methods

Study design and population

The risk factors for intracranial meningioma study consisted of 200 incident cases and 400 controls, matched on age and gender, all from a three county region in western Washington state. One of the main exposures hypothesized to increase the risk for this tumor was ionizing radiation to the head and neck region, of which dental radiography is the largest component of this radiation (12). Although self reported dental radiography over a lifetime was the exposure investigated, concern about possibly poor or biased recall between cases and controls necessitated the addition of a study validating lifetime dental radiography.

Interview and recall enhancement

All subjects were interviewed in-person by a trained interviewer. Although it was not feasible to blind the interviewer to case-control status, all three interviewers were trained to perform the study procedures in a standardized fashion. Each subject first constructed a lifetime calendar on multiple 8 by 11 inch sheets in landscape orientation, and was asked to recall where they had lived, important life events, and when they occurred (figure 4.1). Subjects were asked to recall each different dentist they had seen in their life, beginning usually with the most recent and going back in time (figure 4.2). If they could not recall the name of the dentist, they were asked to recall anything that they could remember about that dentist and office, including approximate dentist age, gender, type of practice (general practice vs. specialty), and office address or location. Interviewers were trained to not allow more than 10 'gap years' between sequences of specific dentist provided care episodes, and to use additional probes to elicit recall, as previously done by Preston-Martin (81). Subjects were asked to recall the first year of care, the last year of care, the total number of visits and total number of dental radiographic visits for each dentist visited. Next, subjects were asked to recall whether they had had specific dental procedures performed, such as partial dentures, root canals, crowns, orthodontic treatment, or whether they had had trauma to individual teeth. The tooth and service year of each tooth extraction, root canal, crown/ bridge or trauma was marked on a tooth chart (figure 4.3), so that each tooth was accounted for. A dental model of teeth and common dental restorations was shown to subjects, and subjects looked in their mouth to ascertain the status of all teeth. The interviewer was trained to go back over the list of dentists in figure 4.2, and additional dentists were commonly recalled and added to the list after subjects remembered additional dental procedures that were performed. Specific questions about other dental radiographs were also asked, such as full mouth series, panoramic and cephalometric radiographs, and pictures and props of these machines and films were shown to subjects to help augment recall. Near the end of the interview, which lasted on average 128 minutes for cases, and 112 minutes for controls, each subject was again asked to review each dentist recalled and check if they had visited any additional dentists. Cases complete two additional sections including the symptoms of their tumor and the mini mental state exam, and this explains why their interview time was slightly longer.

Overall strategy to assess lifetime dentists and completeness

Three data sources were used: the subject's recall of a dentist at the interview, claims data from a large dental data warehouse at Washington Dental Service (WDS) for the time period of 1993 to 2001, and dental records gathered from dentists from 1940 to 2001. This allowed for two separate, two source capture-recapture analyses; one from 1993 up to 2001; and the other from 1940 to 2001. Using the general method previously described for animals, we 'captured' one list of dentists seen by subjects through the interview, and then 'recaptured' another group of dentists using either the WDS data warehouse or dental records received from dentists. Some of these dentists will be found in both lists, some only in one or the other, and, by using a straightforward formula, the number found from neither source can be calculated (see figure 4.4).

Capture-recapture assumptions.

Capture-recapture methodology has four basic assumptions: 1) the study population is a closed population, that is, no in or out migration; 2) sufficient information is available in each source to uniquely match subjects; 3) the source lists are independent of each other; and 4) all members of the population have an equal opportunity of being captured (90). In addition, some authors state that all identified subjects must be members of the population, and that this should be verified [ref].

Unique identification of dentists

In order to perform these capture-recapture analyses, each dentist from each source needed to be uniquely identified to verify if that name was present on more than one source list, so that it could be potentially matched. 54 percent of dentists names were recalled at the time of the interview, and by comparing partially recalled names and practice location plus other information from dental directories (American Dental Directory, 1947-2001, American Dental Association) we were able to positively identify 81 % of dentists in the validation record subset, and 65% overall . For example, identifications were made by finding that Dr. X was the only practicing orthodontist in town Y from 1965 to 1968, or that Dr. Z was the only general dentist in his 40's on Main Street from 1976 to 1983. Besides needing to identify dentists for matching, we were also concerned that some subjects might recall dentists that were never seen and did not exist, so we also worked to rule out dentists that could not have been visited.

Matching dentist names

Dentist names were deemed a match if the first and last names were identical, if the last name and the unique location were identical, or if all available information demonstrated a unique match. Some dentists names were recalled and listed phonetically, and small variations in spelling would usually yield positive identification and potentially a match. Only a few dentists names (less than five) were difficult to match because the name was not recalled and other details were too vague or not unique.

Data sources: Washington Dental Service (WDS)

WDS is a Delta Dental Plan third-party insurer and is the largest dental insurance carrier in the state of Washington. It provides services to more than 1 million consumers through more than 2,000 dentist providers in the state. A computerized relational database, called the WDS Data Warehouse project, consists of all WDS claims data since 1993. Subject searches were done of the database by last name, first name and birth date. Alternative search strategies for unmatched names included last name, first initial or middle initial and birth date. All dental procedures located in the database for each subject also indicated the name, specialty, and address of dentists who provided the treatment. Dentists and treatment by each dentist that was performed between the earliest available data warehouse date (1992-1993) up to the day before the subject's interview (1996-2001) was eligible for inclusion. We queried the dental histories of 178 of 200 cases, and 398 of 400 controls and found that 32% of cases had visited dentists in the data warehouse, and 33% of controls. The study was reviewed and approved by the human subjects committee at the University of Washington

Data Source: Dental records

We contacted dentists by mail and telephone to gather available dental records for a subset of 80 of 200 cases and 100 of 400 controls. This subset was generally selected by enrolling consecutive cases and controls as first became available for the main case-control study. Dentists were sent letters and an abstract booklet designed using the Total Design Method (93). On the second page of the eight page booklet, they were specifically asked to list the names and addresses of other dentists that had treated the subject. Some dentists sent only photocopied records, and these records were abstracted to find the names of additional prior, referring or specialist dentists. Finally, 49 dental records were abstracted in dental offices, and the question of other treating dentists was gleaned from the actual chart or by asking the dentist and their staff. Availability of dental records decreased with the elapsed time since the last dental visit, ranging from 82% for records from subjects visited within the last ten years to less than 10% for records gathered from dentists seen 30 years and more, similar to what has been previously shown (94). We gathered in total 205 dental records for 91 cases, and 255 dental records for 108 controls.

Statistical analysis

Capture-recapture techniques were applied to estimate the total number of dentists that meningioma subjects has seen over their lifetime (90;95). The first data sources used were the WDS data warehouse and subject recall for years 1993 to the interview date. The nearly unbiased estimator, X was given by the formula: $X = (B * C)/ (A+ 1)$ for the population that is on neither list was calculated, where B= dentists found on WDS claims, but were not recalled, C = dentists recalled at the interview but not found in WDS, and A= dentists found on both lists (ref). The total population of dentists (N) is the sum of A, B, C and X. An approximate unbiased estimate of the variance of N derived by Seber was used (96). The corresponding 95% percent confidence intervals (95% CI) of N were calculated using the formula: 95% CI = N +/- 1.96 SQRT Var (N) (97).

The second data sources used were the dental records for the same time period of 1993 to the interview date. In this way, we were able to estimate the dentist population for this short but recent time span using independent sources, allowing comparison to evaluate possible source dependence. Of the five assumptions previously mentioned, the independence of among source lists has been shown to be crucial (98). Substantial dependence between lists so that dentists are more likely to be on both lists (positive dependence) or less likely to be on the lists (negative dependence) can significantly alter estimates of N to be far from the true values. If there is positive dependence, which is likely in the case of dental records, then the total population will be underestimated; if there is negative dependence, then the population will be overestimated. We evaluated the dependence by comparing the population values between the two, two-source methods. If the estimates are similar, then minimal dependence is likely to be present; if they are substantially different, then dependence is likely occurring.

We also performed multiple capture-recapture analyses using the dental record – subject recall sources, and stratified by years since the last dental visit, and also by the age of the subject at the interview, to explore how recall completeness varied by subject age and elapsed time. Analyses were done separately for cases and controls. Finally, since we hoped to measure how accurate any reference standard for lifetime dental radiographic utilization would be, we compared the dental records obtained from dentists forgotten and compared them to dental records of recalled dentists, and measured the ratios of forgotten to recalled dentists for characteristics such as dentist specialty, mean years of care, rates of dental radiographic visits. Analyses were done using Microsoft Excel XP (Microsoft Corp, Redmond, WA).

Results

Population description

The mean age (range) of the case subjects was 56.4 (18 – 88) years, and 55.4 (18-90) years for control subjects. More controls had attended at least some college than case subjects (65.3% vs. 52.5%). Case participants reported a median of 34 years of dental care before the reference date, and controls, 36 years.

Description of dentists recalled

The 200 case participants recalled in the interview that they had visited 1014 different dentists over their lifetime (mean = 5.1), while the 400 controls recalled visiting 2212 (mean = 5.5). The number of lifetime dentists recalled ranged from 1 to 14 for cases, and from 1 to 15 for controls, but varied only slightly by the age of subject. The youngest age category of subjects of less than age 30 saw 4.0 dentists, and ten year age groups of subjects from 40 to 70 visited between 5.0 to 6.3 lifetime dentists. Case subjects over 80 recalled visiting substantially fewer lifetime dentists (3.7 versus 6.1 for controls). Most dentists were general dentists, 88% for cases, 86% for controls, and 97% case and 98% control dentists were located in the US or within the US military when the care was provided.

Comparison of two 2-source capture-recapture population estimates for 1993 to 1996-2001 (reference date)

In table 4.1, the WDS – interview recall and dental record – interview recall capture-recapture population estimates with 95% CI are presented. For 178 cases, the total number of dentists was estimated to be 144 (95% CI, 127-162) using WDS data, and 141 (95% CI, 127 – 156) using dental records. The percent completeness of recall at the interview was relatively high, and ranged from 88 to 86%. Over this 3 to 8 year time period, the number of dentists visited averaged 0.7 from recall and obtained records, and 0.8 using capture-recapture for the WDS query and the dental records. In the bottom part of table 4.1, similar data for controls is displayed. The WDS and interview data sources estimated 426 (95% CI 381 -471) total dentists, while the dental record – interview sources estimated only 342 (95% CI 314 – 366). The percent completeness of recall varied from 74% using WDS to 93% using the dental records. The average number of dentists was 0.79 for both WDS and dental records using recall and records, but the actual number was estimated to be 1.1 for WDS and 0.9 for dental records.

Total lifetime dentists overall and by time elapsed

Next, we used the dental records from all years to estimate the total lifetime dentists for cases and controls. The top of table 4.2 shows the results for all 200 case participants.

We estimated the total number of lifetime dentists to be 1237 (95% CI, 1154 – 1317), or 6.2 (95% CI, 5.8-6.6) mean lifetime dentists, versus 5.1 found at interview, 5.2 estimated using additional records obtained from dentists. Completeness of recall was estimated to be 82% overall.

The bottom of table 4.2 shows estimates of the number of lifetime dentists for 400 control subjects. We estimated the total lifetime dentists to be 2592 (95% CI 2432 – 2753), corresponding to 6.5 (95% CI 6.1 – 6.9) mean lifetime dentists, compared to 5.5 recalled at interview and 5.6 estimated after obtaining the validation sub study dental records. Completeness of recall was 85% overall for controls. Also presented in table 4.2 are the number of total dentist and completeness of recall estimates by the elapsed time from the interview to the last dental visit. Not surprisingly, both cases and controls show 100% completeness for dentists they are presently visiting, although the completeness decreases as time elapses, down to only 63% complete for dentists last seen 20 or more years by the cases, and 76% complete for controls.

Recall completeness by age of subject

In table 4.3, the number of lifetime dentists is displayed for cases and controls by the age of the subject. Older subjects show lower estimated recall completeness than younger subjects, and cases show lower completeness than controls. The recall completeness declines in an almost linear fashion as the subject age increases for the cases (83% to 65%), although a trend is not apparent for the controls (80% to 79%).

Types of dentists and dental procedures forgotten.

Although we cannot obtain dental records from most subjects forgotten at the interview, since they are unidentified, about 34% of these unrecalled dentists were identified either through WDS or through the dental records obtained via the validation substudy. Table 4.4 shows a comparison of the 'forgotten' records with those of recalled records. WDS (recent years) and dental record sources (all years) are shown separately. Striking differences are apparent. Far more 'forgotten' dentists are specialists such as oral surgeons, endodontists and periodontists, compared to dentists that were recalled. In addition, these 'forgotten' dentists were visited for a far shorter time interval than the recalled dentists (0.53 vs. 3.6 visits per person-year for WDS; 1.0 vs. 7.6 visits per person-year for all dental records).

When dental radiographic visits are compared, the 'forgotten' dentists had fewer dental radiographs taken, since they were seen for far fewer years, but the rate of dental radiographic visits was six times higher for panoramic, ~50% higher for bitewing, and variably higher for full mouth radiographs. If all of the 'forgotten' dentists took identical rates of dental radiographs as the recalled dentists, then the proportion of undercounted radiographs would be equal to the proportion of dentists not recalled, which we have shown to be from 15 and 18%. However, these 'forgotten' dentists were more likely to be specialists that were visited for only one or two visits, and, even though these dentists frequently take radiographs at these visits, it appears most likely from table 4.4 that the number of radiographs missed would be less than 15 to 18%, and would be roughly half, or 7.5 to 9% more radiographs than those recalled. This estimate is the product of the ratio of dental care visits between forgotten and recalled dentists (0.53/3.6=0.15) and x-ray visits between forgotten and recalled dentists (((1.5 +2.7+6.8)/3)=3.1); 0.15 x 3.0 = 0.5 or 50% of 15 to 18%.

Discussion

In this study, we have presented a new method to assess the completeness of validation study reference standards in an investigation of dental x-ray utilization. The number of dentists forgotten by subjects was likely to be about 1 in 5, even though we went to great lengths to improve subject recall. The number of lifetime dentists we estimated for this population, between 6.2 to 6.5, is substantially more than what has been found, 4.3 to 4.5, in comparable studies in western US with subjects of similar age (58 vs. 55) and education (12), although comparisons between differing populations may be limited by potential confounding. Of the 17 studies that have measured dental radiographic utilization as a risk factor for different types of tumors, only 4 of 17 ascertained the dentists names, and only 2 of 17 completed gathering dental records to check if some dentists were forgotten (12;99). We could not locate validation studies for other exposures that have measured the completeness of the reference standard, although prior concerns with completeness have been raised (81;89). As our analyses indicate, even gathering records for some or all of a sample will still yield an underestimate of the total number of providers ever visited – some dentists will still not be located.

The differences between cases and controls in the estimated lifetime dentists were relatively small, although the greater number of dentists among controls likely illustrates the higher educational status of this group. The recall completeness was relatively similar between cases and controls, but older case subjects had less complete recall than similarly aged control subjects, as did all cases for dentists visited more than 20 years previously. Although the majority of brain tumor cases had minimal sequalae from their tumor, some of the older case participants may have had some reductions in their memory capacity, and older controls may have had better overall cognitive functioning.

Limitations

The main limitation of this analysis is that not all capture-recapture assumptions were probably met. Assumption one, having a closed population, is met, since the population of dentists seen by the meningioma subjects is closed and fixed; assumption two, independence between sources, is met by the WDS capture-recapture analysis, since we did not need to know the previously recalled dentists by the subjects to query the database. However, for the dental records, we relied upon the subject's recall of dentists names to gather these records, so this assumption is partially violated. Assumption three requires 'equal catchability' of dentists, and this is generally fulfilled with the WDS estimate, since essentially all dentist treatment performed on WDS member subjects will be found in the database. The dental record estimates partially violate this assumption, since dentists visited many years ago are less likely to be recalled or to have their records be available. Assumption five requires that all dentists recalled or located actually were the dentists of these subjects. We found three cases where recalled dentists were certain that the subjects had never received care from them, and also found two instances where subjects, especially older age, recalled a physician's name in place of the dentist. In all other cases, if dentists indicated that the subject had not been seen, they admitted that records from the same era had been purged, and they could not be certain that they had lost or disposed of the record, and that the dentist could not remember the subject's name. However, given that 3145 dentists were recalled by 600 subjects, it is likely that less than 5% (157) of the dentists recalled were actually seen, and assumption five appears to have been met.

What is the likely effect of the dependence between the dental records and subject recall of dentists? The lack of congruence between the WDS and dental records for the recent dental care is an indicator that positive dependence occurred. The WDS records show only 74% completeness, while the dental records show 93% completeness, and the estimates of total dentists are substantially different (381 vs. 314). Since the WDS records fulfilled most assumptions, they are more likely to be accurate. We separately found that controls recalled fewer dentist names than cases for dentists in this recent time period of less than 10 years (89% correct recall for cases vs. 68% correct for controls). Thus, there are multiple indicators that controls forgot more dentists in the time period just before the interview date. This may reflect a generally lower level of motivation for recalling a large amount of mundane information over a two hour time period, compared to someone who recently had had a brain tumor and was eager to help investigators find the general causes of this condition.

The effect of the positive dependence between records and subject recall for all years is more difficult to assess, since we have no additional large source of dentist information before 1993. We located two additional completely separate and independent sources of dentists and dental records, the US Military records and a large database of endodontic treatment in the University of Washington School of Dentistry (n=42,000 records), but both sources only yielded a small number of subjects with records (less than 30), and the capture-recapture estimates of completeness, between 71 and 89%, were thus unstable. Given other work with capture-recapture, the safest conclusion is that the number of lifetime dentists estimated here is conservative, and the percent completeness overestimated.

Strengths

Some of the strengths of this study include the ability to use the separate and independent source of dentists and dental treatment from WDS. In addition, by creating several two source capture-recapture analysis, the analyses are computationally simpler and the results are less ambiguous (97). The alternative is to use log-linear methodology where multiple models and estimates of the total population are calculated, and, although dependence can be modeled, choosing among these models can be problematic (97).

Dental radiographic utilization

Although we cannot be certain how much dental care and dental radiography were missed because the dentists were forgotten, it can be estimated. Many of the forgotten dentists and related dental care were seen for short time periods, but much of the treatment, such as endodontic (root canal) treatment, consisted of multiple dental radiographic procedures. The overall effect of using only dentist's recall in a validation study of dental radiographic procedures would be to underestimate the number of dental providers seen, and number of dental radiographs taken. For example, if subjects were found to overestimate the number of dental radiographs taken, compared to this unverified standard, by 30%, and the imperfect standard was missing 30% of the dentists (and a comparable amount of dental radiography), in actuality, the subjects would have recalled exactly the correct the number of dental radiographic visits. Thus, the general effect of verifying the reference standard will be to minimize any apparent over-estimation of recalled dental visits, while under-estimation of visits of the unverified standard would show even greater underestimation if the more complete, verified standard was used. We also observed some case-control differences, so the difference between the verified reference standard and the original standard may result in changes in the overall estimate of association in an epidemiologic study, although most of the differences were small.

In summary, we have demonstrated the use of capture-recapture methods to ascertain the completeness of sources of lifetime dental utilization. Despite intensive interviewing, subjects forgot at least 15 to 18% of the dental providers they had visited. Using an un-verified reference standard may result in inaccurate results when performing validation studies. We recommend that capture-recapture methods be used to assess the completeness of validation studies in healthcare utilization.

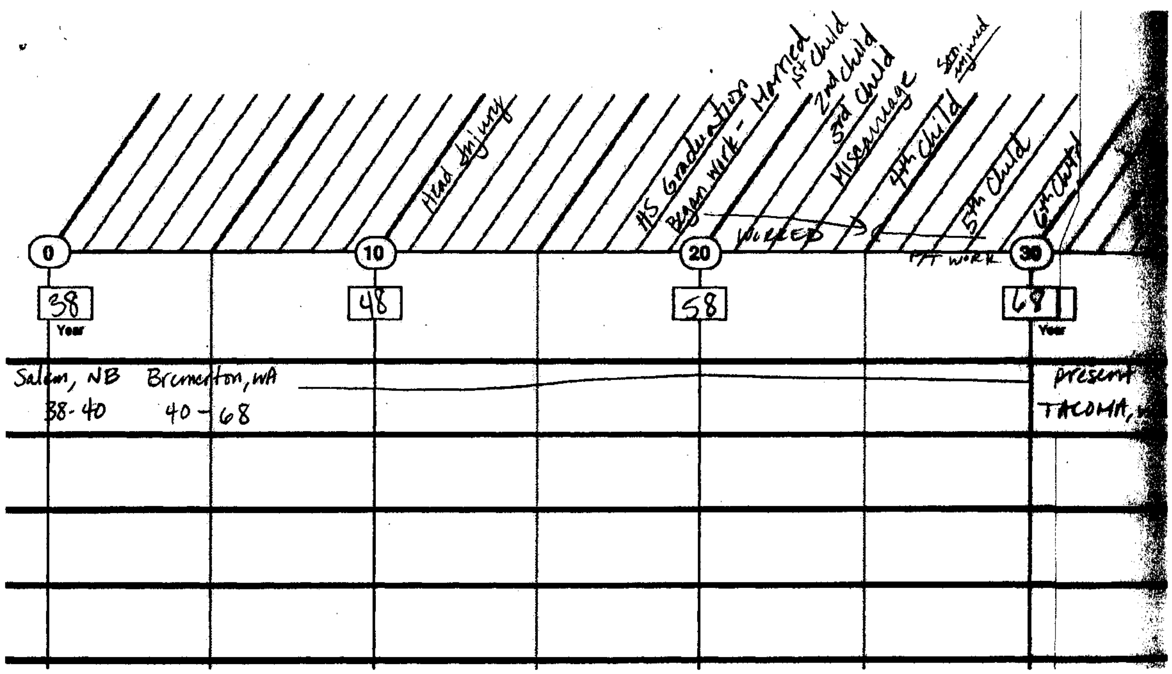


Figure 4.1 Example of lifetime events calendar from the meningioma risk factor study. Subjects first completed a life events calendar indicating where they had lived, when they had graduated from school, been married, had children and changed jobs.

Meningioma Exposure Questionnaire
96 March 12 Page 5 of 37

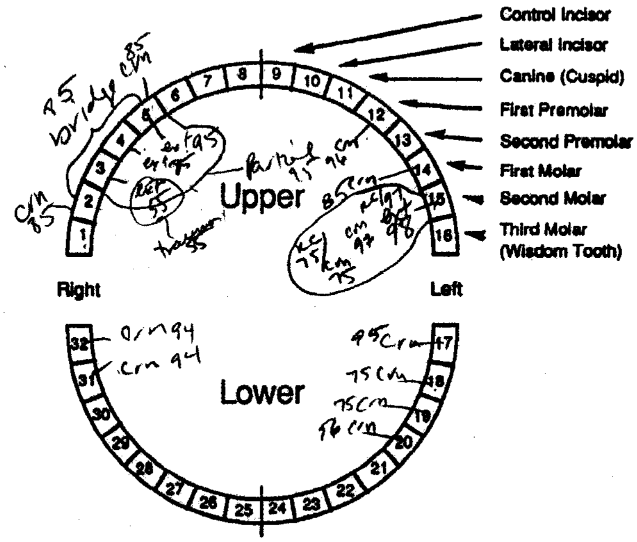
Study ID [redacted]

Location	Dentist	a. Year started	b. Year ended	c. X-rays	d. Visits	e. Refusal
Tacoma	[redacted]	98	99	2	01	1
Tacoma	[redacted]	94	97	2	01	1
Tacoma	[redacted]	84	87	2	01	1
Tacoma	[redacted]	74	77	2	01	1
Australia	?	63	63	1	00	1
Tacoma	[redacted])	91	91	1	00	1
US Army		50	53	2	01	1
Ft. Collins, Co	?	55	55	1	00	1
Hazel Park, MI	[redacted]	36	38	1	00	1

Figure 4.2 Example of list of lifetime dentists from the meningioma study. After completing the life events calendar, subjects were asked to recall each dentist they had visited, the year treatment started, the year treatment ended, beginning with the most recent, and going back in time. They also were asked to if they had ever had dental x-rays, and the number of dental x-ray visits for each dentist.

Meningioma Exposure Questionnaire
96 March 12 Page 7 of 37

Study ID [redacted]



tooth	year of extraction	year of cap (or crown)	year of trauma	year of root canal
1	19__	19__	19__	19__
2	19__	1985	19__	19__
3	1955	19__	1955	19__
4	1995	19__	19__	19__
5	1995	1985	19__	19__
6	19__	19__	19__	19__
7	19__	19__	19__	19__
8	19__	19__	19__	19__
9	19__	19__	19__	19__
10	19__	19__	19__	19__
11	19__	19__	19__	19__
12	19__	1996	19__	19__
13	19__	19__	19__	19__
14	19__	1995	19__	19__
15	1998	1975	19__	1975
16	19__	19__	19__	19__

tooth	year of extraction	year of cap (or crown)	year of trauma	year of root canal
17	19__	1995	19__	19__
18	19__	1975	19__	19__
19	19__	1975	19__	19__
20	19__	1996	19__	19__
21	19__	19__	19__	19__
22	19__	19__	19__	19__
23	19__	19__	19__	19__
24	19__	19__	19__	19__
25	19__	19__	19__	19__
26	19__	19__	19__	19__
27	19__	19__	19__	19__
28	19__	19__	19__	19__
29	19__	19__	19__	19__
30	19__	19__	19__	19__
31	19__	1994	19__	19__
32	19__	1994	19__	19__

Other Notes:

Tooth	Comments
15	2nd rc/crn done 1997
__	

Figure 4.3 Example of tooth chart completed in subject interview. Interviewers attempted to account for the status of each tooth of each subject; whether it had been extracted, crowned or replaced with a bridge, had a root canal, or previously had trauma, and the approximate year that this occurred.

Figure 4.4 Hypothetical example of a lifetime of dental treatment for one subject. The subject was born in 1940, and interviewed for the study in 1995 at the age of 45. She recalled visiting 4 different dentists, and available records obtained from her previous dentists indicated a fifth dentist was recently seen for two visits that she forgot. However, a sixth dentist was also visited by the subject in 1958, at the age of 18, for removal of her 3rd molars (wisdom teeth). Forgotten dentists and dental care are not easily ascertained by using only subject recall, even when buttressed by obtaining available records.

Dentists and dental care over time:

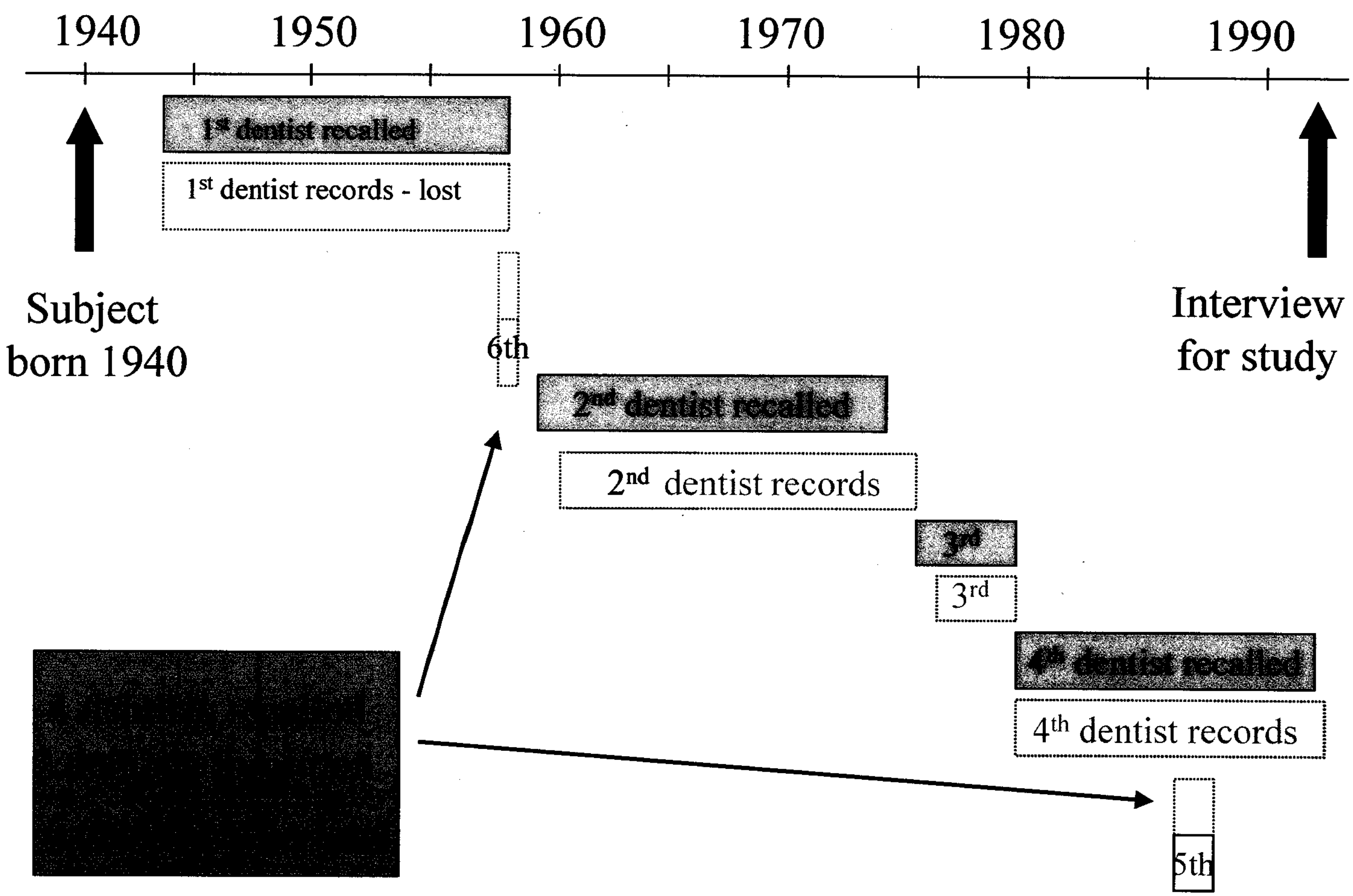
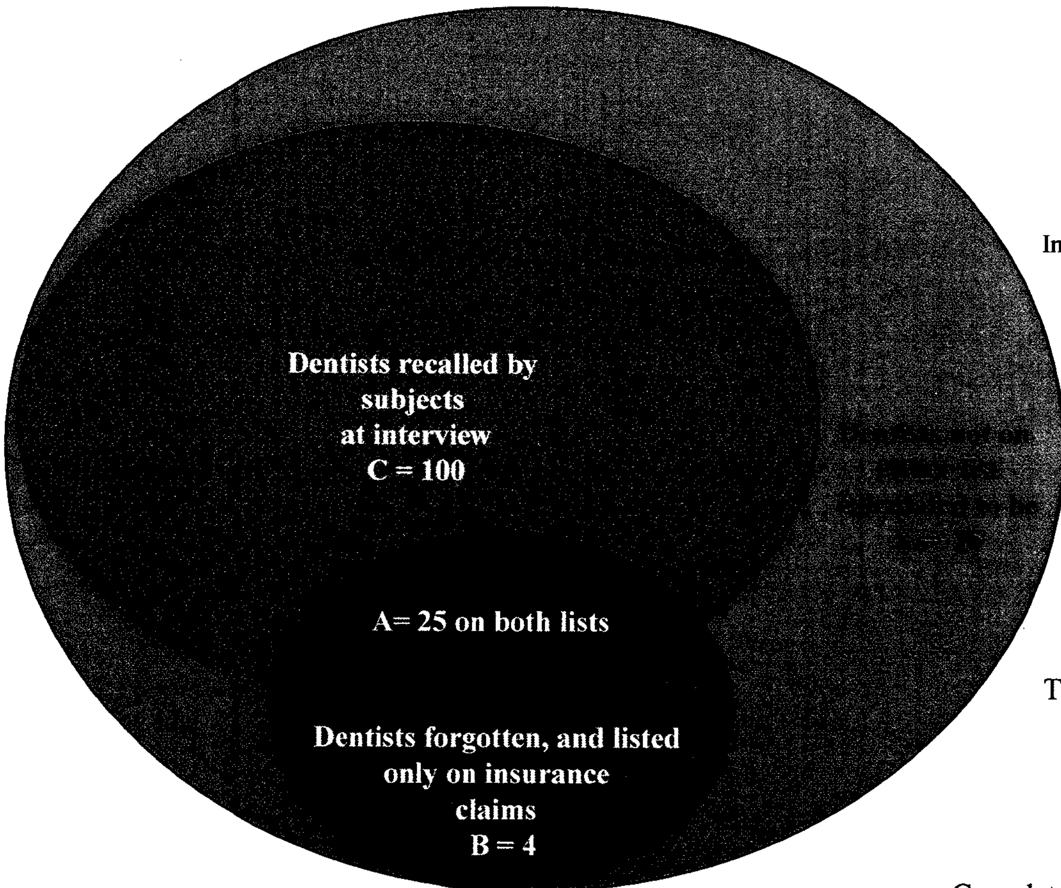


Figure 4.5 Capture-recapture analysis for WDS insurance claims and case subject recall 1993 to 2001. Subjects first recalled 125 dentists (A+ C) for this time period at interview, and WDS insurance claims database was later queried for dental treatment by the same subjects (A + B). Twenty five dentists were located on both sources (A), while 100 dentists (C) were recalled but not found in the WDS database, and 4 dentists (B) were only found in the database but were forgotten. Using a Nearly Unbiased Estimator (NUE) formula described in the text, the number of dentists visited but forgotten and not on the WDS database can be calculated. The percent completeness of either source can be calculated using the formula A/(A+B) or A/(A+C), which shows that 86% of dentists visited were recalled by the dentist at the interview. The values in this figure correspond to the top part of table 4.1.



Insurance claims		Recall at interview: yes	Recall at interview: no
	yes	25 (a)	4 (b)
	no	100 (c)	X (x)

X= (b * c)/(a +1)

X= (4*100)/(25+1)

X= 15

Total dentists = N = A+B+C+X

N = 25+4+100+15

N= 144

Completeness of subject recall = A /(A+ B)

86% = 25/(25+4)

Total dentist population recalled = 129, but calculated to be N=144

Table 4.1 WDS and dental record capture-recapture method to estimate the total number of dentists and recall completeness.

For the time period January 1, 1993 to the subject's interview date (February 1996 to June 2001)

Cases (n=178)

Record Source	Dentists identified				Total Dentists	Total Dentists 95% confidence int.		Recall *** Percent Complete
	Recall only	Record only	Recall & Record	Neither Recall nor Record *		Lower **	Upper **	
WDS data warehouse	100	4	25	15	144	127	162	86%
Avg. no. of dentists			0.70		0.8	0.7	0.9	
Dental Records	95	4	30	12	141	127	156	88%
Avg. no. of dentists****			0.70		0.8	0.7	0.9	

Controls (n=398)

Record Source	Dentists identified				Total Dentists	Total Dentists 95% confidence int.		Recall *** Percent Complete
	Recall only	Record only	Recall & Record	Neither Recall nor Record *		Lower **	Upper **	
WDS data warehouse	248	24	68	86	426	381	471	74%
Avg. no. of dentists			0.79		1.1	1.0	1.2	
Dental Records	277	3	39	23	342	314	366	93%
Avg. no. of dentists****			0.79		0.9	0.8	0.9	

Legend

*	Dentists not recalled nor on records calculated using the nearly unbiased estimator (see text)
**	Confidence intervals calculated using the Serber variance formula (see text)
***	Recall percent complete calculated according to a/a+b standard formula (see text)
****	Average number of dentists calculated by dividing the total dentists visited by the number of subjects

Table 4.2 Number of dentists and recall completeness by years since last dental visit.

Cases (n=200)

last dental visit before interview in years	Dentists identified				Total Dentists	Total Dentists 95% confidence int.		Recall ***
	Recall only	Record only	Recall & Record	Neither Recall nor Record*		Lower **	Upper **	Percent Complete
presently visiting	73	0	3	0	76	76	76	100
0 to 5	134	10	78	17	239	225	253	89
6 to 10	82	6	18	26	132	106	158	75
11 to 19	172	7	18	63	260	204	317	72
20 or more	393	10	17	128	548	470	806	63
All years ****	883	29	134	191	1237	1154	1317	82
Average lifetime dentists per person	5.1		5.2		6.2	5.8	6.6	

Controls (n=400)

last dental visit before interview in years	Dentists identified				Total Dentists	Total Dentists 95% confidence int.		Recall ***
	Recall only	Record only	Recall & Record	Neither Recall nor Record*		Lower **	Upper **	Percent Complete
presently visiting	172	0	2	0	174	174	174	100
0 to 5	314	7	88	25	434	412	455	93
6 to 10	179	8	21	65	273	219	328	72
11 to 19	327	6	13	140	486	354	618	68
20 or more	1076	4	13	308	1401	1068	1733	76
All years ****	2071	24	137	360	2592	2432	2753	85
Average lifetime dentists per person	5.5		5.6		6.5	6.1	6.9	

Legend

* Dentists not recalled nor on records calculated using the nearly unbiased estimator (see text)

** confidence intervals calculated using the Serber variance formula (see text)

*** Recall percent complete calculated according to a/a+b standard formula (see text)

**** summary for all years was calculated separately, and adding up each cell in the table may yield a slightly different summary value

Table 4.3 Number of dentists and recall completeness by subject age at interview.

Cases (n=200)

Subject age (years)	Dentists identified: Recall only	Record only	Recall & Record	Neither Recall nor Record*	Total Dentists	Total Dentists 95% confidence int. Lower **	Upper **	Recall *** Percent Complete
Less than 45	222	6	29	44	301	261	342	83
45 to 59	278	13	58	61	410	370	450	82
60 to 74	238	9	33	63	343	294	392	79
75 and older	142	7	13	71	233	168	298	65
All years ****	883	29	134	191	1237	1154	1317	82

Controls (n=400)

Subject age (years)	Dentists identified: Recall only	Record only	Recall & Record	Neither Recall nor Record*	Total Dentists	Total Dentists 95% confidence int. Lower **	Upper **	Recall *** Percent Complete
Less than 45	371	8	32	90	501	430	572	80
45 to 59	769	9	62	110	950	871	1029	87
60 to 74	483	4	29	64	580	512	649	87
75 and older	452	3	11	113	579	440	718	79
All years ****	2071	24	137	360	2592	2432	2753	85

Legend

* Dentists not recalled nor on records calculated using the nearly unbiased estimator (see text)

** confidence intervals calculated using the Serber variance formula (see text)

*** Recall percent complete calculated according to a/a+b standard formula (see text)

**** summary for all years was calculated separately, and adding up each cell may yield a slightly different answer

Table 4.4 Forgotten versus recalled dental specialists and dental radiographic visits.

	WDS Records 1993 to 2001					Dental Records 1940 to 2001				
	Forgotten		Recalled		Ratio Forgotten/ Recalled	Forgotten		Recalled		Ratio Forgotten/ Recalled
	number	percent	number	percent		number	percent	number	percent	
Total Individual Records	32		107			20		256		
Dentist specialty										
general practice	19	59%	92	86%	0.7	7	35%	214	84%	0.4
oral surgeon	3	9%	1	1%	**10.0**	3	15%	7	3%	**5.5**
endodontist	6	19%	2	2%	**10.0**	6	30%	15	6%	**5.1**
orthodontist	0	0%	11	10%	0.0	0	0%	7	3%	0.0
pediatric dentist	0	0%	0	0%	na	0	0%	7	3%	0.0
periodontist	3	9%	0	0%	inf	2	10%	6	2%	**4.3**
prosthodontist	1	3%	0	0%	inf	1	5%	4	2%	**3.2**
other specialist	0	0%	1	1%	0.0	1	5%	2	1%	**6.4**
Mean years of dental care (person-years)	0.53		3.6		0.15	1.0		7.6		0.13
	number	**rate/pyr**	**number**	**rate/pyr**	**ratio**	**number**	**rate/pyr**	**number**	**rate/pyr**	**ratio**
Dental Radiographic visits										
Bitewing	15	0.88	222	0.58	**1.5**	21	1.05	1425	0.73	**1.4**
Full mouth	2	0.12	17	0.04	**2.7**	1	0.05	109	0.06	0.9
Panoramic	3	0.18	10	0.03	**6.8**	7	0.35	95	0.05	**7.2**
Cephalometric	0	0.00	0	0.00	na	0	0	16	0.01	0.0

Legend

Both cases and controls are grouped together since the sample size was too small to permit separate analyses.

pyr = person-years

Chapter 5: Lifetime recall of dental x-rays: accuracy, precision, and differential bias.

Objectives: Ionizing radiation to the brain is one putative risk factor for intracranial meningioma, a common benign brain tumor. Dental x-rays may have contributed to the development of these tumors, but quantifying such exposures poses multiple challenges. As part of a case-control study examining dental radiography as a risk factor for intracranial meningioma, we: 1) developed methods to facilitate recall of lifetime dental x-ray visits; 2) determined the agreement of recall and records of dental x-ray visits over a lifetime by subjects; and 3) assessed if differential bias between cases and controls occurred.

Methods: First, aids to enhance recall of distant, mundane events, such as dental x-ray visits, were developed and used with in-person interviews. Subjects created lifetime calendars of events, listed towns they lived in, listed dentists they had seen, self examined their teeth, were asked to recall specific dental procedures, and were shown pictures of types of dental radiographs and machines. Second, dental records were retrieved for a subset of 91 of 200 cases and 108 of 400 controls from multiple sources, including subjects' dentists, military records and a dental insurance data warehouse. Records were then compared with subjects' recall of x-ray visits to determine record-recall agreement and measure if differential bias occurred.

Results: 174 dental case records and 224 control records were available. Compared to records, cases and controls over-reported full mouth (+0.23, +0.15) and bitewing (+1.7, +1.3) mean visits, and under-reported panoramic (-0.12, -0.05) and cephalometric (-0.05, -0.01) mean visits, respectively. Correlations indicating precision between recall and

records for cases and controls were: full mouth, 0.33, 0.23; bitewings, 0.65, 0.75; panoramic, 0.50, 0.60; and cephalometric, 0.82, 0.57, respectively. Analysis by the time elapsed since reference date showed cases over-reporting full mouth x-rays in the 9 years before reference date more than controls, while reporting was similar between cases and controls for earlier time periods

Conclusion: With the exception of full mouth x-ray visits the nine years just before the interview, dental x-ray visit recall was reasonably accurate and precise, and bias present was generally non-differential.

Introduction

With a few important exceptions (2;100), much of what we know today about the relationship between low-level ionizing radiation and tumors comes from studies that have relied upon the long-term recall of the exposures by study subjects (6;18;94;101). Because of well-publicized evidence that acute, high-level radiation exposure is carcinogenic, concerns have arisen that cases with tumors will recall more radiation exposures than controls. The accuracy of long-term recall has only been studied sparingly, mainly because few sets of accurate, long-term records of exposure are available. One pioneering study of risk factors for leukemia performed in the 1960's found that subjects forgot about 75% of the medical and dental radiographs taken in the preceding 10 to 15 years when compared with the records (99). Twenty years later, a case-control study of salivary gland tumors attempting to validate the lifetime recall of dental radiography found that both cases and controls over-reported the number of full mouth radiograph visits compared with records, although they found no differential recall between cases and controls. Several limitations were noted by the authors. These included evidence that dental charts did not list all radiographs taken, the concern that dentists may not be forthright in the reporting of x-rays for the study, and difficulties in obtaining complete records. In addition, they showed that the rarity of obtaining dental charts more than 22 years old and the resultant small sample for analysis limited the interpretation of their results (81). In addition, recent validation studies have demonstrated that relying solely on the subject to identify the only sources of the reference standard – the dentist in this case – is problematic. If the subject forgets some of these sources, the result will be incomplete standards by which to compare (89;102). Finally, the accepted methods of reporting both the accuracy and precision of recall have advanced since these reports were published (88).

We recently performed a study of the risk factors for intracranial meningioma, a benign brain tumor, in which ionizing radiation from dental radiography is a hypothesized risk factor. Because of remaining uncertainty about the accuracy of long-term recall of dental radiographs, we performed a study to validate the recall of a lifetime of dental radiography. We hoped to address these validation study limitations in previous studies by 1) gathering more records, and older records; 2) checking the completeness and validity of the dental record; 3) relying on other sources for the recall of prior dental care; 4) examining several types of dental radiographs commonly used; and 5) abstracting some dental records in-person, rather than relying upon the dentist and staff to do so.

In addition, we also hoped to facilitate the recall of these lifetime exposures by using building on the methods previously used (81), methods developed by cognitive psychologists, and adding additional cues and probes related specifically to dental treatment.

Thus, the overall aims of this study were fourfold; first, to describe the methods used to facilitate long-term recall; second, check and optimize the dental record reference standard; third, assess the accuracy of recall for dental x-rays by comparing it to the dental record; and finally assess if differential bias occurred between cases and controls.

Methods

Study population

The main investigation was a population-based case-control study of the risk factors for intracranial meningioma, a benign brain tumor. To be eligible for the study, cases had to be 18 years or older, residents of King, Pierce, or Snohomish counties in western Washington state, and diagnosed with an incident intracranial meningioma that was histologically confirmed during life between January 1, 1995 and June 30, 1998(103). To allow comparability with controls, all cases had to have a telephone prior to diagnosis and to speak English. Human subjects committees at the University of Washington and the Fred Hutchinson Cancer Research Center approved the study.

Over 3.5 years beginning January 1995, 238 eligible patients with incident meningioma were identified, with a mean age 56.3 years (SD 15.6) and with 69% percent women.

With their physician's approval, eligible patients were invited to participate in the study, and 200 (84%) did so. For the 38 (16%) who did not, 24 refused and 14 were lost at some stage of the recruitment process. Those who participated (n=200) were similar to those who did not (n=38) on age, sex, marital status and county of residence but not race. Those who participated were significantly more likely to be white than those who did not.

From the same three Washington counties, we identified two controls per case, each matched to the corresponding case on age within 5 years and on sex, using one of two techniques. The first was random digit telephone dialing using the Mitofsky-Waksberg sampling protocol (104;105). Over 97% of the region's households had telephones, based on the 1990 census (106). Because random digit dialing proved to be inefficient for identifying controls 65 years or older, part way through the study, we adopted an alternative technique in this group using Medicare eligibility lists obtained from the Health Care Finance Administration. From the lists for the target counties, we randomly selected potential controls matched to each case on birth year and on sex. We mailed them a letter explaining the study and requesting their participation. Of the estimated number of eligible controls, 55% participated in the study with random digit dialing (n = 355), and 67% with Medicare eligibility lists (n = 45).

Interview

Information about demographics and past exposures was collected during a structured in-person interview after obtaining informed consent. Although all three interviewers were trained to administer questions to all subjects in a standard fashion, they were not blinded to the case-control status of subjects. Some of the questions were linked to a reference date. For the cases, this date was the date of the surgery at which tissue establishing their diagnosis was obtained. For the controls, the reference date was the same as for their matched case.

Study subjects were questioned about the dental care over their lifetime (figure 5.1). They began by constructing a calendar indicating all places they had lived and important life events. On this calendar, for each place they lived, subjects indicated periods of regular dental care during which time they saw a dentist at least once a year and whether they had routine dental bitewing films taken, and the total number of visits. Second, they were asked to account for each of the 32 teeth in their mouth by counting them, and then indicate on a tooth chart whether each tooth had been extracted, crowned, traumatized, or had had a root canal, and the year of these events. In previous studies, people have been shown to recall accurately dental conditions such as number of existing teeth, and number of teeth with root canals, fillings, crowns and bridges (107). Questions about which dentists performed these procedures and whether dental x-rays were taken helped subjects to recall additional dentists and x-rays. Third, subjects were asked about dental procedures that affect the entire mouth, such as seeing a gum specialist, wearing braces, having fixed or removable bridges, or complete dentures. They were asked once again which dentists, which years, and if x-rays were taken. Fourth, three specific dental radiographic procedures – panoramic, lateral cephalogram, and full mouth x-rays - were extensively described to subjects and they were shown pictures of machines commonly used from 1930's to 1990's. Samples of x-rays from these machines were also shown to subjects. They were asked if had such examinations done, the total number, and what year and with what dentist were they performed. Finally, near the end of the interview, which lasted about 2 hours, they were asked to review the list of dentists and dental care to see if they could recall any additional details, and also whether we could contact their dentists to review their dental records. All but three subjects consented to these record requests.

Dental records

Using this information and the lifetime calendar described above, interviewers collected names and addresses of all dentists seen. Next, we looked up the names of these dentists and checked their address, graduation and retirement dates from the *American Dental Directory* (108) to see if treatment from the recalled dentist was plausible. If subjects could not recall the dentists' name, they were asked to recall any details about the person, including their age, gender, specialty, office address, etc. By using this additional information, we were able to positively identify 76% of the dentists in the validation sample. Initially, we included approximately the first 60 cases and controls from the main study into the validation study. For practical reasons, the recently seen dentists from both cases and controls must have been identified by name so that we could contact them. Later on in the study, additional records were gathered from other cases and controls on the basis of convenience. We obtained the dental records from the dentists by using a modification of the Total Design Method by Dillman (93). Briefly, we sent a one page letter to dentist announcing the study and notifying them of our request for records (Appendix B.1). We did not inform them of the case or control status of their patient until after the records were received or the status of the records ascertained. One week later, we sent another letter and a dental abstract booklet for the dentist and staff to complete. We gave dentists the option of sending a photocopy of the dental record substituting for parts of the booklet if the treatment history was long. If dentists did not respond they were sent an additional letter and booklet from 3 to 15 weeks later. If they did not respond to this second request, they were contacted by telephone and the request was faxed to them. For offices that failed these three attempts, we offered to abstract the charts in their office, which usually resulted in the faxing of the records or an in-office abstraction visit by one of three trained abstractors. Using these methods, we had a 92% overall response rate, although included in these responses were responses that the records no longer existed, the dentist was dead, the patient was never seen in the office, or the records were not available or lost. We also requested US Military dental records for all subjects who indicated military service.

As previously indicated (81;109), dental records availability declined as time elapsed from the present day to the last visit the subject was seen, so that few records were available if dental care occurred more than twenty years previously. State law in Washington state only requires dentists to retain patient charts for five years if they are an adult (110).

In-office abstractions and abstractions done of photocopied records were done by one of three trained abstractors. A random sample of 20 records each was reabstracted to check for reliability. The initial finding was that almost all errors were due to the definition of a full mouth x-ray survey, and this definition was further refined as 10 or more films taken of different parts of the mouth and teeth at one visit. Some root canal visits included more than 10 films at one visit, but these where of the same tooth, and did not match the description given to patients. After further training, and another sample of 20 records, the inter-rater reliability of recorded dental bitewing x-ray visits was shown to have a kappa of 0.78 for abstractor 1 to 2, and 0.81 for abstractor 1 compared to 3.

A second sample of the validation study used the Washington Dental Service data warehouse project, one of the first dental data warehouses in United States and available since 1993, to query for dental treatment of all case and control subjects. Information about dental procedures submitted for payment, date of service, number of procedures, treating dentist's name and address, dentist specialty, and subject's first date of eligibility were the main variables used. Matching of subject names was done by using the last name, first name or initial, and birth date. Of the 600 subjects, 198 Subjects names were found in the database, 182 had had dental treatment, and 168 had had dental treatment before their interview date. Since the insurance warehouse only has treatment records for subjects when they had WDS insurance, some treatment was performed and not captured in the database. To allow a fair comparison between recall and record, we adjusted the subject years of recall to correspond with that of the WDS records. For example, if a subject recalled 9 bitewing visits from 1990 to 1998 (one per year), yet WDS records were only available from 1994 to 1998, then the recall was adjusted to include only one bitewing per year, or 5 visits.

Evaluating the dental record reference standard

Because of past concerns that the dental record may not list all radiographs exposed, we developed an overall model of dental x-ray use that included exposed, stored, recorded and billed categories of radiographs, and that each category may differ in the number of radiographs (see chapter 3). By comparing multiple sources and types of dental records, we showed that dental bitewing, full mouth and panoramic radiographs recorded are within 10 to 15% of those exposed. However, we also identified that root canal therapy usually requires the exposure of from 3 to 6 radiographs, and these films are usually not recorded or billed. Other similarly conducted work has shown that orthodontic and US military dental work commonly results in the under recording of dental radiographs. Because of these discrepancies, for some analysis indicated, we added one additional bitewing radiograph visit for each root canal procedure that was recorded. Likewise, we added one cephalometric and one panoramic radiograph for each orthodontic procedure lasting at least two years if no radiographs were recorded.

We also were concerned that not all dentists who were seen for care by our validation subjects were recalled, and hence the reference standard would be flawed. Since a national database of dental treatment in the United States is lacking, we have previously shown that by using capture-recapture methodology, we can estimate the total number of dentists that our subjects had seen in their lifetime. Using dual two source capture-recapture analyses, we estimated that our cases recalled 82% of lifetime dentists, and controls, 85%. Much of this care was for only one or two visits, but the number of radiographs taken was substantially more than an average dental visit. Part of this forgetting is taken care of in our analyses since we also had records from WDS, and some of this care was forgotten by subjects. The dental care forgotten but represented on WDS records was found to be about 5%, so that another 10% (100% - (85% + 5%))of dental records were neither recalled nor were records identifiable. We did not adjust for this discrepancy, although our dental record reference standard is thus still slightly incomplete.

Analysis

Figure 5.2 shows a hypothetical but common illustration of a lifetime of dental treatment for a 45 year old women subject interviewed in 1995. She recalled five specific dentist provided sequences of care, some of which involved single and others that involved multiple visits, procedures and dental x-rays. The main unit of analysis was thus each recalled or recorded episodes of dental care from one individual dentist in a unique dental office, from a single visit (usually to specialists for a specific procedure) to over fifty separate visits (for many years of care from the same general dentist).

We calculated the mean number of radiographs recalled and recorded for each dental x-ray category, and did this separately by case and control status. We used the discrepancy score (102), or the number of radiographs recalled minus the number or radiographs on the reference standard , as an absolute measure of accuracy. Since relative measures of accuracy are not well developed in validation studies, we developed a simple measure of relative accuracy by using the number of radiographs recalled divided by the number of radiographs on the records, multiplied by 100 to have the percent of radiographs recalled.

For example, if 3.0 mean radiographs were recalled, and 2.0 mean radiographs were recorded, then the discrepancy score would be 3.0 – 2.0 = 1.0 visit, while the percent recalled would be 3.0 / 2.0 x 100 or 150%. Measures of precision were determined used Spearman's correlation coefficient. We measured differential bias by comparing the discrepancy score for cases with that of controls. We used the paired sample T test to test the null hypothesis that there was no difference in discrepancy scores between cases and controls.

Sensitivity and specificity were also calculated, using cutoff points generally close to median values; 4 or less vs. 5 or more for bitewing visits; and 0 vs. 1 or more full mouth, panoramic and lateral cephalogram visits. Only dental procedures before the interview date were considered. For comparisons between cases and controls, the reference date or day of surgery was used.

Results

Subjects' age, sex, race, and educational status in the overall study and in the validation sub-study are shown in Table 5.1. Cases and controls were similar with respect to age and sex in both groups. More controls attended at least some college than cases. Cases recalled 5.3 mean lifetime dentists; controls, 5.6. The mean number of any type of dental x-ray visit recalled was 22.0 for cases, and 20.7 for controls; for the validation sample, 23.5 x-ray visits for cases and 22.9 visits for controls. For the validation sample, the mean number of complete dental records per subject were 2.6 for the cases, and 1.9 for controls. The oldest dental records retrieved for cases was 1940; for controls, 1953.

Table 5.2 shows the types of dental records that were retrieved by case-control status. Dental records were abstracted in-office, photocopied records were abstracted, although the majority of records came from abstract booklets that were mailed. Few US military records were available (18 of 127 requests sent or 14 %). Washington Dental Service insurance records showed treatment before the interview date for 59 cases and 108 controls.

Table 5.3 shows the accuracy, precision and potential bias for the four types of dental x-ray visits studied. For bitewing visits, both cases and controls over-reported the number of visits by 48 and 39%, respectively. The recall was relatively precise with correlation coefficients between 0.65 and 0.75. The difference in the discrepancy score was not significant. Panoramic visits were under-reported by both cases and controls. Cases recalled 59% of the recorded visits, while controls recalled 80%. The recall was also relatively precise with values of 0.50 and 0.60. Cephalometric films were uncommon in this population, and so the results are unstable. Both cases and controls substantially under-reported these x-ray visits, recalling only 17 and 50%, respectively, of the recorded visits. The precision was also moderately good. Full mouth visits were over-reported by both cases and controls. The precision of recall was fair to poor, showing correlations of 0.23 for controls to 0.33 for cases.

For bitewing x-rays recalled less than ten year before the reference date, the percent recall was 250% for cases and 163% for controls, which was significantly different; for x-rays recalled ten years or more from the reference date, the percent recall was 106% and 75%.

Since full mouth x-rays are the primary risk factor in the meningioma risk factor study, we further explored the possible differential bias by the time elapsed since the reference date for the two main categories of dental x-ray visits, bitewing and full mouth x-ray. Recall of full mouth x-ray visits by time since reference date is shown in table 5.4 and also figure 5.3. For the nine years immediately before the reference date, subjects over-reported full-mouth series, 227% for cases and 137% for controls (p=.01). For visits ten to nineteen years before the reference date, cases slightly under-reported the correct number (92%), and controls slightly over-reported (125%). For the critical time period 20 or more years before the reference date, when the induction time has been long enough for the exposure to act, cases correctly recalled the number of full mouth x-ray visits (100%) while controls over-reported the visits (150%), which would tend to deflate any true association between these x-rays and meningioma

Discussion

The main finding of this validation study is that we found robust evidence for recall bias – cases recalling more full mouth x-rays than controls – for the time period 0 to 9 years before the reference date or time of surgery, but this differential bias disappeared as the number of years before the reference date increased. In general, both cases and controls over-reported bitewing and full mouth x-ray visits, under-reported panoramic visits and cephalometric visits.

The recall of both bitewing and full mouth x-ray visits showed a trend of over-reporting, and then relatively accurate reporting as time since reference date increased. Unfortunately, records older than 35 (~1965) to 45 (~1955) years were so infrequent that additional analyses were unstable. However, by using published dental utilization rates for the mid- 1900's (111) we estimated that both cases and controls substantially under-reported dental bitewing and full mouth x-ray visits in the 1930's, 40's and 50's. Thus, it is possible that a general pattern of over-reporting, then accurate reporting, and then inaccurate under-reporting may exist for both bitewing and full mouth x-ray visits. This pattern is consistent with the general decay of memory over time that has been shown (112). Whether cases forgot more or less than controls for this earliest time period, thereby creating bias, can only be speculated. From the previous work using capture-recapture (chapter 4), recall completeness of dentists was less for cases that were older and for dentists seen more than 20 years earlier (tables 4.2, 4.3). In addition, figure 5.3 shows that full mouth x-rays have an odds ratio less than one, beginning in 1952, possibly indicating more forgetting of these visits by cases then controls. Lastly, when we evaluating the correct recall of the dentist's last name by the subject versus time, cases recalled more names correctly for recent years but did substantially worse for dentists seen 50 years ago or more.

Why do cases recall more full mouth visits than controls? Most observers would assume that it is related their having had a brain tumor, and being more cognizant of activities that may have been involved in causing the condition. Interestingly, we asked all cases what they believed caused their tumor, and only a handful mentioned dental x-rays.

Compared to the only successfully conducted dental x-ray validation study (81), we also show over-reporting for the same time period as Preston-Martin for full mouth x-rays, and under-reporting for panoramic radiographs. The over-reporting we noted is less, and may be partly because our reference standards are more complete, and we used more extensive means to help subjects recall the visits.

Some of the study limitations should be noted. Most dental records were not available for time periods greater than thirty years. In addition, we found dentists to dispose of older dental records, even for active long-term patients. That is, if a patient had been seen by the same dentist from 1945 to 1995, usually the 1945 to 1965 part of the record or later would have been disposed of.

This disposal of older records also led to difficultly in determining whether a dental chart was complete or not. The general effect of this uncertainty is to make recall appear worse than it is, by indicating apparent over-reporting. For example, the subject recalls 30 bitewing visits over 30 years. The record only shows 20 bitewing visits over 20 years. If the subject truly saw the dentist back that far, and the dentist disposed of the earliest records, this will lead to apparent over-reporting when the subject was accurate in reporting.

In addition, only some records are available from some dentists for any given subject, and so it is difficult to establish lifetime dental records. The likely effect, however, is to be more stringent in reporting the validity, since a subject may correctly recall a bitewing visit in 1965, but if they said it was with Dr. A, and not Dr. B, who was actually with, our analysis would again show over-reporting.

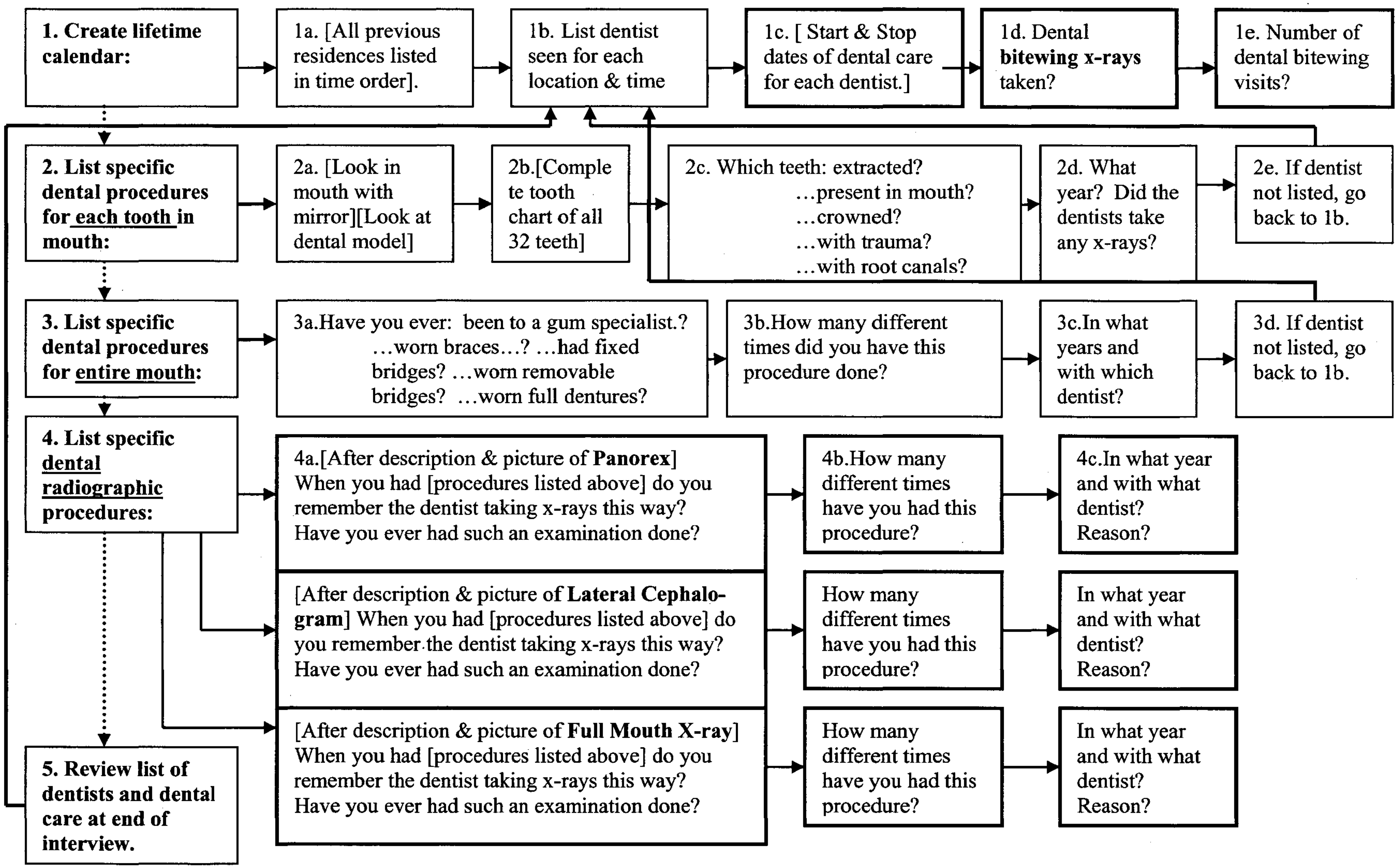
There also could be systematic case-control differences in remembering in our sub-sample. That is, when enrolling most of the sub-sample, we required subjects to be able to recall the name of the most recent dentists they had seen. We had often had to go to the second control matched to the case, since the first control could not recall the dentist's name. However, when we did analyses separately for only the WDS records, which did not rely on subject recall, we could not see any substantial differences in the results.

Some of the strengths of this study should also be noted. Given how mundane and 'forgettable' dental x-ray visits are usually perceived, it is somewhat remarkable, especially for the bitewing visits, how well subjects recalled these events. We attribute this accurate reporting mainly to the high correlation of bitewing visits with the number of years seen by a dentist. In addition, we had a high response rate, so that the records we gathered are unlikely to be systematically different from any not gathered; we gathered more records, and older records than any previous study; and we studied four types of dental x-rays. Finally, by using the data warehouse, we did not have to rely solely on the subject to recall dentist's names, and this allowed us to estimate the number of dentists seen for care but forgotten (see chapter 4).

Further work in the area of facilitating long-term recall is warranted. Additional facilitation of subject recall may be possible, if additional resources are available. For example, many subjects, once queried, were eager to gather more information about the past dental care and if the record information gathered by investigators was systematically given back to subjects, they may be able to further enhance their recall. This study has looked mainly at the average subject values. More research should be done to differentiate between the people with accurate recall and those with inaccurate.

In conclusion, we have shown evaluated the recall accuracy for four common dental x-ray visits, and shown general over-reporting for bitewing and full mouth, and underreporting for panoramic and lateral cephalometric visits. We observed recall bias only for full mouth surveys 0 to 9 years before the reference date.

Figure 5.1 Strategy to facilitate lifetime recall of dental radiography. This schematic figure shows the general strategy and sequence of questions used in the in-person interviews. First, a life events calendar on multiple 8 x 14 inch sheets was constructed. Next, for each location and time period, subjects were asked to recall dentist seen. For each dentist seen, the first and last years of treatment were listed. For this period of dental care, subjects were asked about routine dental bitewing x-rays, and how many total visits they had of these with each dentist. Second, subjects were asked to account for the status of each tooth in their mouth, and whether it had been extracted, crowned, been traumatized, or had a root canal, and the date of each occurrence. Third, subjects were asked about dental procedures involving the entire mouth, such as braces, fixed bridges, and dentures. Fourth, after a detailed description, pictures of the machines and examples of the films taken, they were asked about three specific dental radiographic procedures, Panorex, lateral cephalogram, and full mouth x-rays. Finally, at the end of the interview, subjects were asked to review the list of dentists for additional details. Brackets indicate action and not text; bold outlines indicate key dental x-ray exposure variables.


1. Create lifetime calendar:
1a. [All previous residences listed in time order].
1b. List dentist seen for each location & time
1c. [Start & Stop dates of dental care for each dentist.]
1d. Dental bitewing x-rays taken?
1e. Number of dental bitewing visits?
2. List specific dental procedures for each tooth in mouth:
2a. [Look in mouth with mirror][Look at dental model]
2b.[Complete tooth chart of all 32 teeth]
2c. Which teeth: extracted? ...present in mouth? ...crowned? ...with trauma? ...with root canals?
2d. What year? Did the dentists take any x-rays?
2e. If dentist not listed, go back to 1b.
3. List specific dental procedures for entire mouth:
3a.Have you ever: been to a gum specialist.? ...worn braces...? ...had fixed bridges? ...worn removable bridges? ...worn full dentures?
3b.How many different times did you have this procedure done?
3c.In what years and with which dentist?
3d. If dentist not listed, go back to 1b.
4. List specific dental radiographic procedures:
4a.[After description & picture of Panorex] When you had [procedures listed above] do you remember the dentist taking x-rays this way? Have you ever had such an examination done?
4b.How many different times have you had this procedure?
4c.In what year and with what dentist? Reason?
[After description & picture of Lateral Cephalogram] When you had [procedures listed above] do you remember the dentist taking x-rays this way? Have you ever had such an examination done?
How many different times have you had this procedure?
In what year and with what dentist? Reason?
[After description & picture of Full Mouth X-ray] When you had [procedures listed above] do you remember the dentist taking x-rays this way? Have you ever had such an examination done?
How many different times have you had this procedure?
In what year and with what dentist? Reason?
5. Review list of dentists and dental care at end of interview.

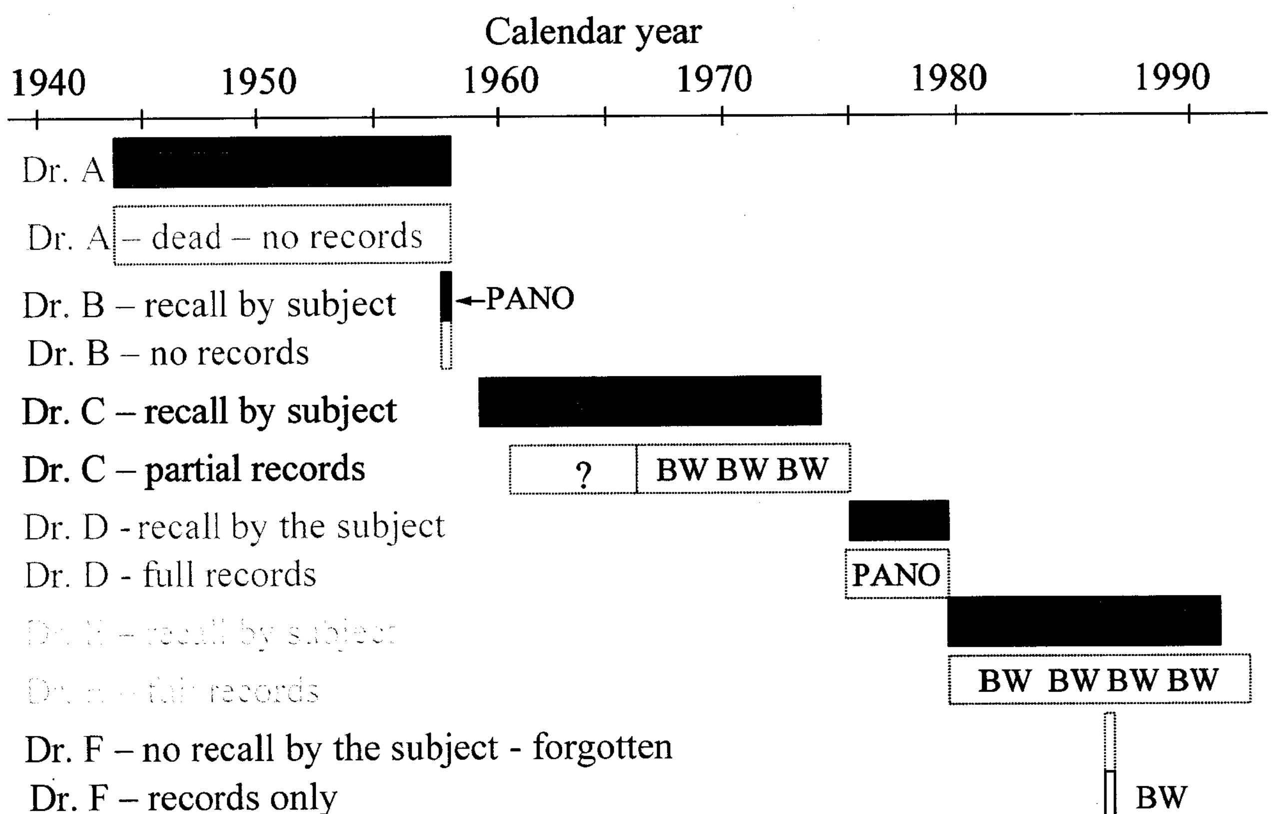
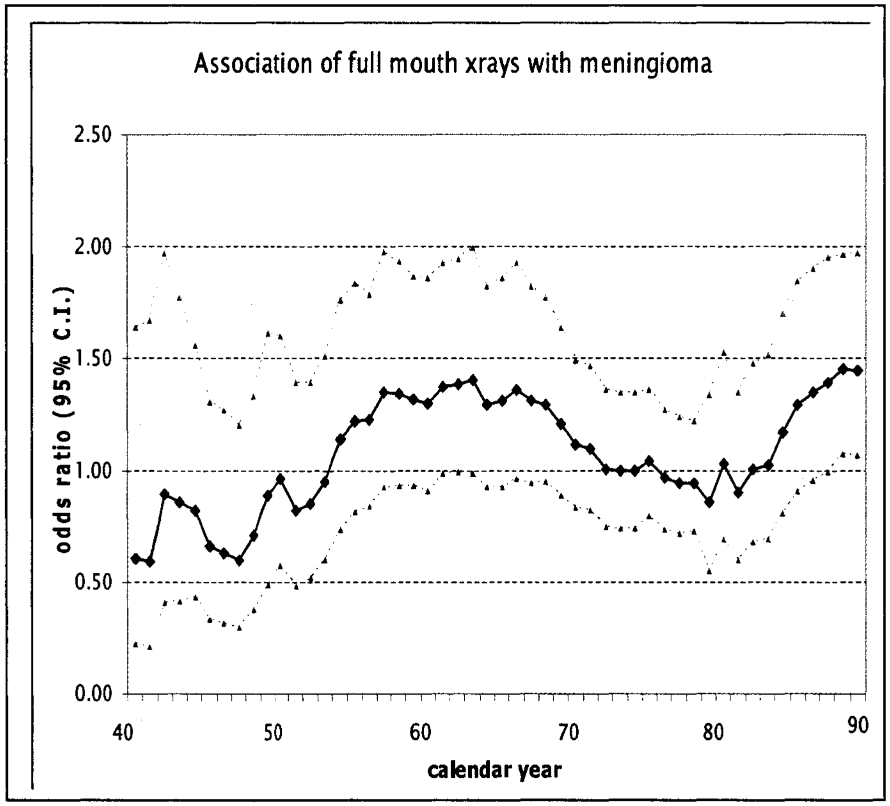


Figure 5.2 Dental care and x-ray visits over time: recall vs. records. This is a hypothetical but common example of a lifetime of dental treatment for one subject. The subject was born in 1940, and interviewed in 1995 at age 45. She recalled visiting 5 different dentists, and available records obtained from her dentists indicated a fifth dentist was recently seen for one visit that she forgot. She recalled 3 bitewing (BW) visits from age 4 to 18, and one full mouth survey visit (FMX), but the dentist had died and no records were available. She recalled two FMX and two BW visits for Dr. C, but only part of the records are available from this office. The subject recalled no x-rays from Dr. D, but the full records show that a panoramic x-ray (PANO) was taken. Each separate dentist-provider series of visits is compared with the recall of dental x-rays from the subject, and is the main unit of analysis for this validation study. For example Dr.E took 3 BW's, but 4 were recalled. The discrepancy score would be 4-3 = + 1 BW visit, or 4/3 x 100% 133% recall of the record.



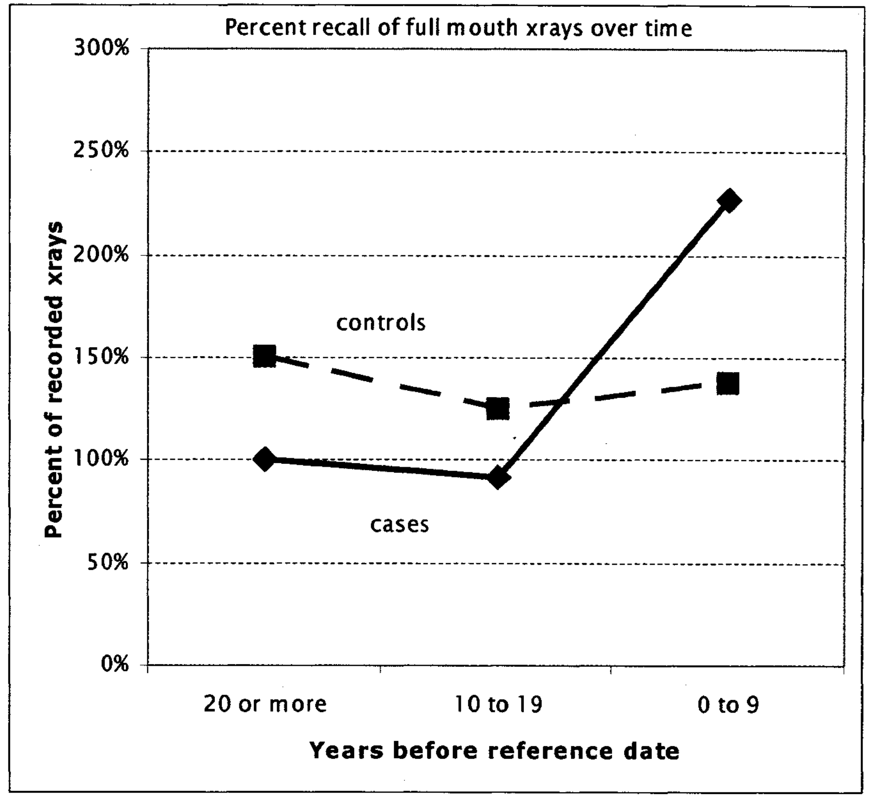


Figure 5.3 Evidence of recall bias falsely elevating the odds ratio. The figure on the left shows an increased risk for meningioma 5 to 9 years before the reference date (1995 to 1998) which corresponds to over-reporting by cases from validation study in the same time period. Since the induction period for meningiomas is 20 to 40 years, the increased risk for meningoma from full mouth x-rays just a few years before the diagnosis is biologically implausible and shows clear evidence that recall bias is adversely affecting the relationship. The validation study also shows that for the two earlier time periods, controls over report slightly more than cases which would attenuate any real association if present. Thus, the second 'bump' of increased risk in the sliding window figure is unlikely due to recall bias.

Table 5.1 Demographics of cases, controls and validation subset.

		Total Sample				Validation Sample			
		Cases (n=200)		Controls (n=400)		Cases (n= 91)		Controls (n=108)	
		number	percent	number	percent	number	percent	number	percent
Mean age		56.4		55.4		53.1		51.5	
Sex	female	143	71.5	286	71.5	70.3		73.2	
	male	57	28.5	114	28.5	29.7		26.8	
Race	white	180	90	373	93	81		95	
	other	20	10	27	6.8	10		13	
Education	less than college	95	47.5	139	34.8	46		39	
	at least some college	105	52.5	261	65.3	45		69	
Total lifetime dentists recalled		1068		2261		510		637	
Mean lifetime dentists recalled		5.3		5.65		5.6		5.9	
	range	1 to 13		1 to 15		1 to 13		1 to 15	
Mean lifetime dental x-ray visits		22. 5		20.7		23.5		22.9	
Complete dental records received		na		na		205		255	
Mean complete dental records		na		na		2.6		1.9	

Table 5.2 Types of dental records retrieved.

	Cases (n=91)		Controls (n=108)	
	number	percent	number	percent
Dental record abstracted in office	18	9%	28	11%
Other dental record abstractions	21	10%	19	7%
Abstract booklet of dental record from dentist	95	46%	83	33%
US Military records	8	4%	10	4%
Insurance records from WDS	59	29%	108	42%
Other records NOS	4	2%	7	3%
All records	205	100%	255	100%

Table 5.3 Dental x-ray recall versus record: accuracy, precision, differential bias.

Subjects	n	Mean Bitewing X-ray visits Recall	Dental Record	Discrepancy Score *	Recall Percent of Actual	Spearman correlation
Cases	174	5.3	3.6	1.7	148%	0.65
Controls	224	4.6	3.3	1.3	139%	0.75

Both cases and controls show overestimation of the actual number of bitewing visits
Cases overestimate more than controls

Subjects	n	Mean Panoramic X-ray visits Recall	Dental Record	Discrepancy Score *	Recall Percent of Actual	Spearman correlation
Cases	174	0.17	0.29	-0.12	59%	0.5
Controls	224	0.17	0.22	-0.05	80%	0.6

Both cases and controls show underestimation of the actual number of panoramic visits
Cases and controls are similar in this underestimation

Subjects	n	Mean Cephalometric X-ray visits Recall	Dental Record	Discrepancy Score *	Recall Percent of Actual	Spearman correlation
Cases	174	0.01	0.06	-0.05	17%	0.82
Controls	224	0.01	0.02	-0.01	50%	0.57

Both cases and controls show large underestimation of the actual number of Cephalometric visits

Subjects	n	Mean Full Mouth X-ray visits Recall	Dental Record	Discrepancy Score *	Recall Percent of Actual	Spearman correlation
Cases	174	0.61	0.38	0.23	161%	0.33
Controls	224	0.34	0.19	0.15	179%	0.23

Both cases and controls show overestimation of the actual number of FMX visits

Cases and controls are similar in this overestimation

* The discrepancy score is the mean recall visits minus the mean dental record visits

Table 5.4. Full mouth x-ray recall versus record: accuracy, precision and differential bias by years before reference date.

Subjects	n	Percent of subjects exposed to FMX	Mean Full Mouth X-ray visits		Discrep. score	Recall Percent of Record	Apparent Odds ratio *	Spearman correlation	Paired sample test ***
			Interview	Dental Record					
Cases	114	23%	0.52	0.23	0.29	227%	1.66	0.20	0.01
Controls **	118	25%	0.35	0.25	0.09	137%		0.30	
			differential bias - cases over-report more than controls ove- report						
Cases **	52	31%	0.46	0.50	-0.04	92%	0.74	0.19	0.64
Controls	52	23%	0.29	0.231	0.058	125%		0.14	
			no significant differential bias - controls over-report, cases under-report						
Cases **	39	41%	0.41	0.41	0.00	100%	0.67	0.43	0.65
Controls	31	6%	0.10	0.06	0.03	150%		-0.02	
			no significant differential bias - controls over- report, cases accurately report						

Legend

* Apparent odds ratio calculated by dividing the recall percent of cases by controls.
This may differ from the actual odds ratio, since multiple records per subject may be present

** Indicates which group is both more accurate and precise in reporting

*** Testing the null hypothesis of no difference in visits

Chapter 6 – Conclusions

The overall goal of this investigation was to determine the absorbed dose of ionizing radiation to the cranial meninges from a lifetime of self-reported dental radiography for the subjects in the meningioma risk factor study. Numerous obstacles and challenges to attaining this goal were encountered but generally overcome. Through separate steps, doses to the cranial meninges were determined, the dental chart reference standard was examined for accuracy, lifetime dental providers were estimated, and self-reported dental radiography compared to the dental chart. In this concluding chapter, we would like to first summarize the key findings from chapters 2 through 5; second, report the main study results showing the risk of meningioma from dental radiography; third, compare and discuss these findings of the observed risk of meningioma per calculated radiation dose with other studies; and finally, discuss further research directions.

Summary of obstacles, prior aims and key findings

The main problems of measuring the lifetime dose of dental radiation to the cranial meninges were identified in chapter one as follows: 1) the dose to brain from dental x-rays is difficult to estimate, and records of radiation output for specific dental x-ray machines are not generally available for machines older than 15 years; 2) the dental record may not show all x-rays taken; 3) subjects may not recall all dentists they have seen in their lifetime, so that the reference standard may be incomplete; 4) dental records older than 5 years since the patient was last seen are not required to be retained and are rarely available, decreasing the chance that a study comparing dental records with self report could be conducted. The aims, key findings and solutions for each identified obstacle are listed below by chapter.

Chapter 2: Ionizing radiation absorbed dose to the cranial meninges of the US population from dental intraoral radiography 1920 to 1993.

The aim of this chapter was to measure the dose to various sites in the cranial meninges from dental intraoral radiography. First, we found all articles that measured the entrance skin exposure from a single periapical radiograph to populations of people in US over the past 73 years, along with the machine technical factors. Large variability in the dose was observed between different dental offices and machines. We next measured the dose to various regions of the cranial meninges for three common dental intraoral radiographic procedures; single periapical, four bitewings, and a full mouth survey. Using linear regression models, we unexpectedly found a large increase in the percent of radiation penetration to the meninges in the late 1950's and 1960's that appeared to be related to large beam size, minimal aluminum filtration, pointed cones and bisecting techniques that were commonly used at the time. The absorbed doses were found to be highest in the anterior region of the base of the brain or clivus. The mean doses in the 1950's and 1960's were in the range of 4 to 6 mGy at the sella turcica and 20 to 30 mGy at the clivus region. Acute radiation doses of 10 to 50mGy have recently been shown to increase the risk for solid tumors (74); thus, it is biologically plausible that single or multiple dental full mouth radiographs in this time period could have caused meningiomas.

Chapter 3: Estimating the true exposure to dental radiography using multiple information sources.

The aim of this chapter was to examine the question of how well the dental record reflects the number of radiographs actually exposed on patients, and to estimate the usual number of radiographs taken for routine dental procedures. This study showed that under-recording of dental radiographs commonly occurs in the dental chart, although the magnitude of the under-reporting depends upon the type of associated procedure. Most separate dental radiographic procedures, such as full mouth, panoramic, or bitewings showed relatively little discrepancy (5 to 10%) between the estimated exposed and recorded, stored and billed radiographs. However, root canal therapy radiographs are usually not recorded or billed, and relying upon the chart or insurance records will result in large underestimation of the actual dental radiograph utilization. Other instances of substantial under recording are also likely to occur, such as with orthodontic and military dental care (113). We also provided estimates for the true number of radiographs exposed for common dental procedures gleaned from several surveys of dentists.

Chapter 4: Capture-recapture methods to determine lifetime dental providers.

The primary aim of this study was to estimate the total number of dentists seen over a lifetime, and to estimate the completeness of subject recall. Results showed that both cases and controls forgot on average about 15% of their lifetime dentists. Older cases forget more of the dentists seen early in their life than controls. In general, with the use of extensive aids to facilitate memory, recall of lifetime providers will be a reasonably accurate reference standard. Studies that do not use extensive recall aids will likely have larger discrepancies in the number of dentists recalled vs. those visited, as shown in past studies by the low number of recalled radiographs and dentists (11;19;114). Additionally, methods such as capture-recapture should be used to check the completeness of the recalled gold standard. A sample of the radiographs recorded by dentists forgotten in the interview shows that these dentists were seen for a shorter amount of time, but the visits had proportionally more radiographs taken.

Chapter 5: Lifetime recall of dental x-rays: accuracy, precision, and differential bias.

In this chapter, the aims were to measure the accuracy and precision of self-reported dental radiographic visits for bitewing, full mouth, panoramic and lateral cephalometric films, and search for differential bias between cases and controls. We found that cases and controls both over-report full mouth, bitewing and under-report panoramic and lateral cephalometric films. Cases over-reported more full mouth visits than controls for the time period 0-9 years before the reference date. No other significant recall biases were noted. Considering the findings from chapters 3 and 4, it is likely that the actual number of exposed radiographs is more than those recorded, and using recorded films adjusted for the dentist under-recording tended to minimize the over-reporting for bitewing and full mouth and further accentuates the under-reporting for panoramic and cephalometric. Thus, except for the time period right before the interview, most all dental radiographic visits are under-reported to various degrees, even after using extensive in-person interview probes and aids to long-term recall such as lifetime calendars. The only other completed dental x-ray validation study showed substantial over-reporting for full mouth and any type of intraoral radiographs for both recent and more distant x-ray visits, but the authors had substantial concerns about the completeness of their dental charts (81).

Overall, these separate but related investigations allow the estimation of the ionizing radiation dose over a lifetime to specific parts of the cranial meninges, given a history of self-reported dental radiography.

Results from the risk factors for intracranial meningioma study

A major aim of the risk factor for meningioma case-control study was to assess the association between a lifetime of dental radiography and intracranial meningioma. The investigation consisted of 200 cases with histologically confirmed intracranial meningiomas matched on age and gender to 400 controls, chosen through random digit dialing or Health Care Financing Administration files. This study showed a significant relationship between six or more full mouth x-rays and the incidence of meningioma (OR= 2.06, 95% C.I., 1.03 to 4.2). No relationship was seen with bitewing, panoramic and cephalometric films. Using a sliding window analysis, the increased risk for meningioma was greatest in the calendar years 1962-64, about 30 years before the reference date, when the odds ratio was about 1.38 to 1.4, or a 40% increased risk (Figures 5.3, 6.1). The risk was larger when only women were included (OR = 1.7, 95% C.I. 2.5 to 1.2) (103). This period of increased risk closely corresponded to the unexpected 'hump' of increased radiation penetration and dose from intraoral dental radiography that was found in chapter two for calendar years 1960 to 1970, peaking in 1967 (figure 2.3).

Discussion of observed risk for the calculated dose

How does this dose and subsequent risk for meningioma correspond to prior studies? No previous work investigating the risk factors for meningioma has measured the dose from dental radiography, although a study of the risk factors for salivary gland tumors measured the dental radiographic dose (12). Studies that have measured the radiation dose from any source and investigated the risk for brain or CNS tumors are listed in table 6.1 (2;6;8;100;103;115;116). The exposure in these studies has ranged from cranial radiation for tinea capitus to atomic bomb blasts. Most of the radiation exposures have been acute ones over a short time frame of seconds to days, except for our study, and the one by Preston-Martin, which included full mouth exposures over many years. Acute exposures have been shown to cause more carcinogenic effect at lower doses than similar levels of chronic exposures (74). However, since one full mouth x-ray years ago may have been of sufficiently high dose to cause a meningioma, one could make the argument that dental full mouth x-rays are actually an acute exposure, since the 16 to 20 film survey is usually taken in 10 minutes. The mean dose to the brain and highest brain doses are all substantially less in the current meningioma study than all the others listed. We also did not find a dose-response, or spatial dose-response relationship (more tumors in base of brain versus fewer on the convexity), although the tumor location data were limited. The mean years of follow-up after the exposure was at least 25 years for most studies, except for the study by Little, which has a short follow-up time and correspondingly lower excess relative risk. The excess relative risk (ERR, calculated as the relative risk minus 1 per Sievert, a measure of the radiation effect on the risk for the tumor, is approximately 10 – 20 for dental full mouth x-rays. This ERR is at least three to six times higher than the ERR for instantaneous exposures such as the atomic bomb blast (2.9), and cohort studies of people treated with high dose radiation for tinea capitus (3.2), cancer (0.19) and hemangioma conditions (2.7), meaning that a greater risk for the same unit of radiation is occurring for dental radiography than other types of radiography or radiation exposure. What is the explanation for this higher than expected excess relative risk for meningioma per radiation dose for dental full mouth x-rays?

Table 6.2 lists both non-causal and causal explanations for the higher than expected excess relative risk per Sievert of radiation, or more elevated risk for meningioma at lower doses to the brain than previously seen.

Non-causal explanations in this context mean that the meningioma study finding is incorrect and that there may be no or minimal increased risk related to dental full mouth x-rays, and no or very small excess relative risk. For example, although the sliding window analyses were adjusted for the subjects' level of education on a three point scale, there may be residual confounding by socio-economic status, which is falsely elevating the odds ratio (OR), approximate relative risk (RR), and hence the ERR. In addition, there still could be recall bias, so that cases incorrectly recalled more full mouth x-rays than controls, falsely elevating the OR and related ERR. However, chapter 5 showed that this is unlikely, especially in the time period where the risk factor study shows an elevated risk, although the number of controls exposed to full mouth x-rays in these early years is low, creating some statistical uncertainty. There is also a possibility that the imprecisely recalled full mouth x-ray visits resulted in non-differential misclassification that has falsely elevated the OR, although this rarely occurs (117). Finally, for non-causal explanations, through multiple tests and analyses, it is possible that this elevated ERR is incorrect and occurred by the play of chance alone. Since the analyses were limited and most planned a priori, and three earlier studies(6;8;114) have found a similar effect with full mouth x-rays, we believe this is an unlikely explanation.

Causal explanations for this elevated excess relative risk are also listed in table 6.2. First, it appears likely that both cases and controls forgot their earliest exposures to dental full mouth x-rays, with the cases possibly forgetting more than controls. In figure 6.1, there are four related figures showing the recall of dentist's last names, number of lifetime dentists, the odds ratio for the association of meningioma and full mouth x-rays, and the recall versus record comparisons, all by case or control status. Figures 6.1A and 6.1B both show a general decline of recall going further back into time, with cases and controls closely matching the level of recall except for the earliest time point, where cases forgot more than controls. Figure 6.1C, the sliding window analyses, shows the falsely elevated risk just before the interview, then no risk, then an increased risk, and then the risk decreasing to less than zero for the earliest time points, indicating that early full mouth x-rays were protective. Instead, it seems more likely for this earliest time period that cases forgot more full mouth x-rays than controls. Finally, in figure 6.1D, cases and controls both over-report, and then more accurately report during the studied time periods. The few old recall and record comparisons that we have collected, and increased number of 'don't know' responses in these early time periods suggest that many full mouth radiographs were forgotten in the earliest time period, as does external dental utilization data of dental radiographs available from external sources (111).

Second, as shown in figure 6.2, dental radiography is relatively unique among diagnostic radiography since the x-ray tube and electrical source is in close proximity to the head and the human body during examinations. Some *in vitro* and animal model studies have shown a potentiation of the carcinogenic effect of ionizing radiation if non-ionizing radiation from electrical sources occurs simultaneously (118;119). It is possible that this or other unknown biological mechanisms are at play to augment the carcinogenic effect of dental radiation.

Third, dental ionizing radiation also affects other organs, such as the thyroid gland, and this gland has been shown to affect the growth of meningiomas (120). The radiation dose to the thyroid was approximately 6 times higher than the dose to the pituitary gland, indicating that the subjects in this study had substantial radiation doses to their thyroid gland. A new, large case-control study will show that dental radiography is associated with low birth-weight infants, possibly through an effect on the thyroid gland (121).

Fourth, we were not able to measure the individual radiation dose given by each dental x-ray machine; we only used the estimated mean exposures for each year of the study from Chapter one, and used the same values for both cases and controls. It is possible that the cases had higher doses than the controls, and the effect of this error would be elevate the overall dose and effect and reduce the ERR into a more plausible range. It is also possible that the controls had higher doses than the cases, and this potentially could erase any observed association.

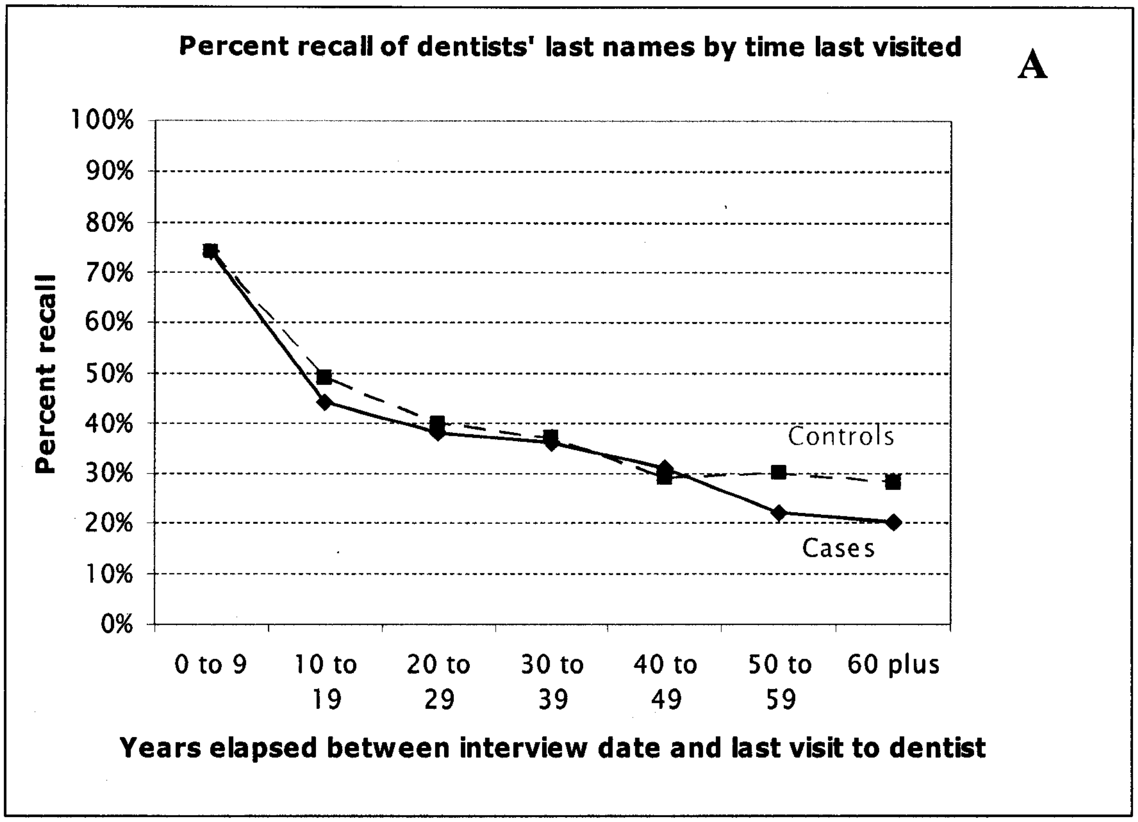
Finally, if our dental dosimetry estimates from chapter one are too low, then the ERR per Sievert would be falsely too high. However, our dose estimates are similar to previous point estimates given in published papers (24;38), except for the 1950's and 1960's, in which our doses are *higher* than the published estimates, which, if anything, would lead to an ERR that is falsely too low.

Assuming that our dose estimates and the excess relative risk per Sievert is correct, how would these data fit into the general dose-response curve shown in chapter 1, figure 1.3? Our data would generally be plotted slightly above the supra-linear curve in the lower left hand corner. The supra-linear curve relationship recently has been given more support from studies such as the atomic bomb life span study than previously thought (74). This dose-response relationship means that at lower doses there is proportionally more tumorigenic effect than at higher doses, and it has far-reaching implications.

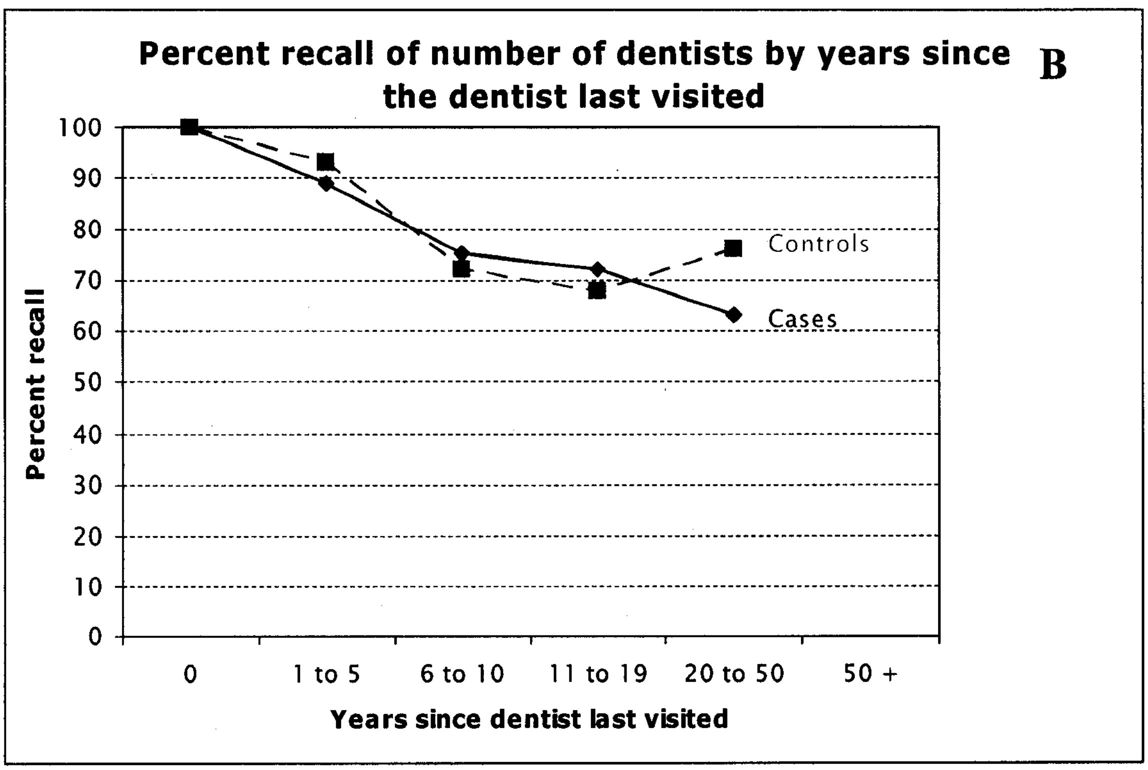
Future research directions

This investigation has suggested additional research opportunities. First, research should be done to find the individual factors associated with both good and poor long-term recall, such as age, gender, education, Mini-Mental State Examination score, etc. Some initial analyses suggest that subjects who forget dental x-ray visits may systematically differ from those that report too many visits. There may be some factors associated with recall that generalize across a wide variety of exposures and outcomes. Second, since the validation sub-study data can potentially be viewed as a data set with missing values, multiple imputation methods could be used to develop a better exposure measure than using self-reported dental x-ray visits. The meningioma risk factor analyses could be done again with this imputation dataset, and may yield interesting results. Third, most Washington state department of health dental x-ray machine radiation output records are available for recent years. Since it is plausible that modern day machine radiation output for any dentist or office is correlated with earlier machine output, a method to extrapolate dose backwards into at least the 1960's would help to answer some of the possible explanations in table 6.2. Fourth, computer simulations are now used to estimate the radiation dose to various anatomic structures for therapeutic radiation regimens (122). These programs basically simulate the traverse of one single photon through specific human tissues, and then the program is run ten to one hundred million times to simulate an entire course of radiation treatment. Similar methods could be used to better estimate the cumulative dose and subsequent risk from dental radiography to the meninges and other organs such as the thyroid. Finally, more basic and epidemiological work should be conducted to test the hypotheses that dental radiography may have unique qualities that are tumorigenic.

Figures 6.1A, B. Recall of dentist's names and total lifetime dentists by time since interview or reference date. The two panels (A, B) show the commonly observed decay of long-term memory as a function of time for dentist's last names and the total lifetime dentists. Cases and controls have almost identical recall until the earliest time periods, in which controls have more complete recall than cases

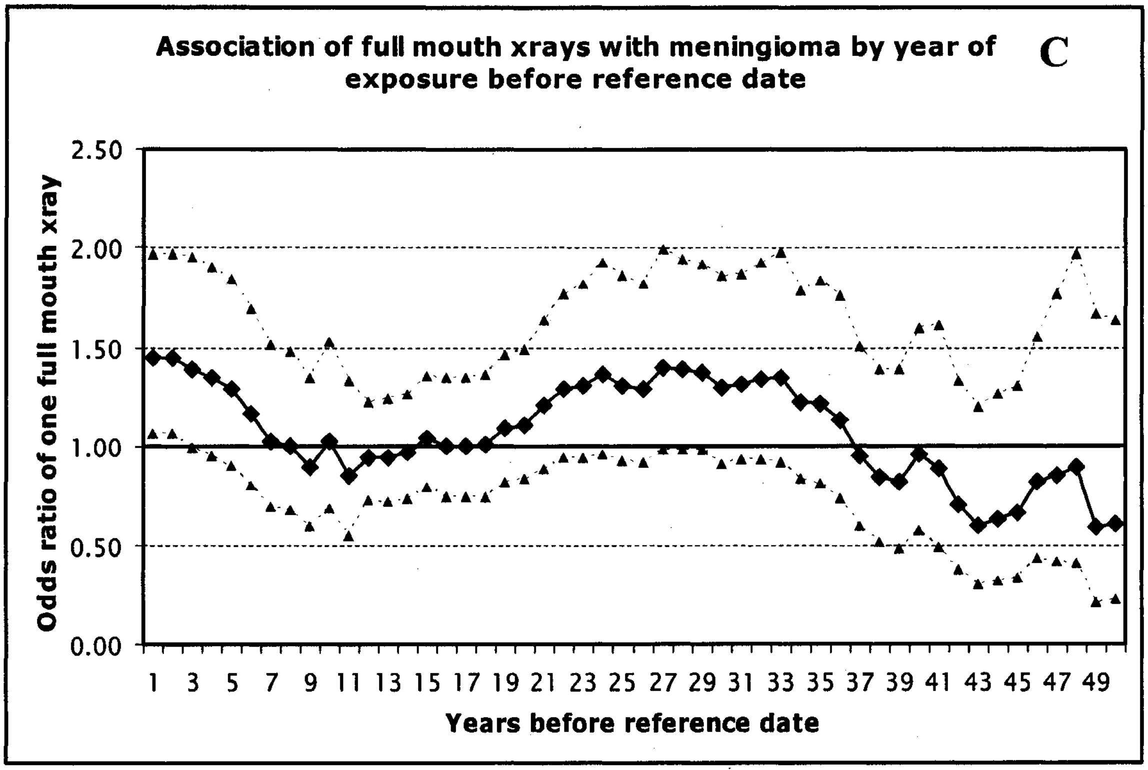


Percent recall of dentists' last names by time last visited
A
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent recall
Controls
Cases
0 to 9
10 to 19
20 to 29
30 to 39
40 to 49
50 to 59
60 plus
Years elapsed between interview date and last visit to dentist

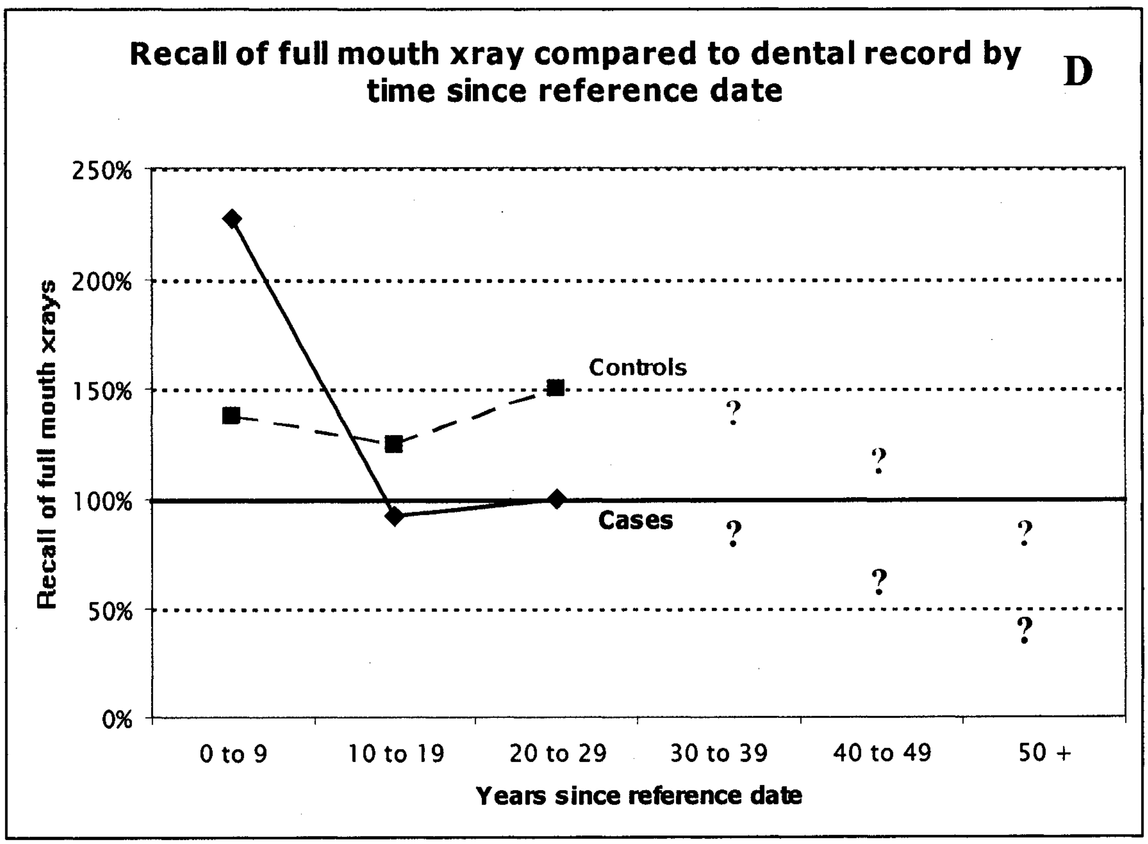


Percent recall of number of dentists by years since the dentist last visited
B
100
90
80
70
60
50
40
30
20
10
0
Percent recall
Controls
Cases
0
1 to 5
6 to 10
11 to 19
20 to 50
50 +
Years since dentist last visited

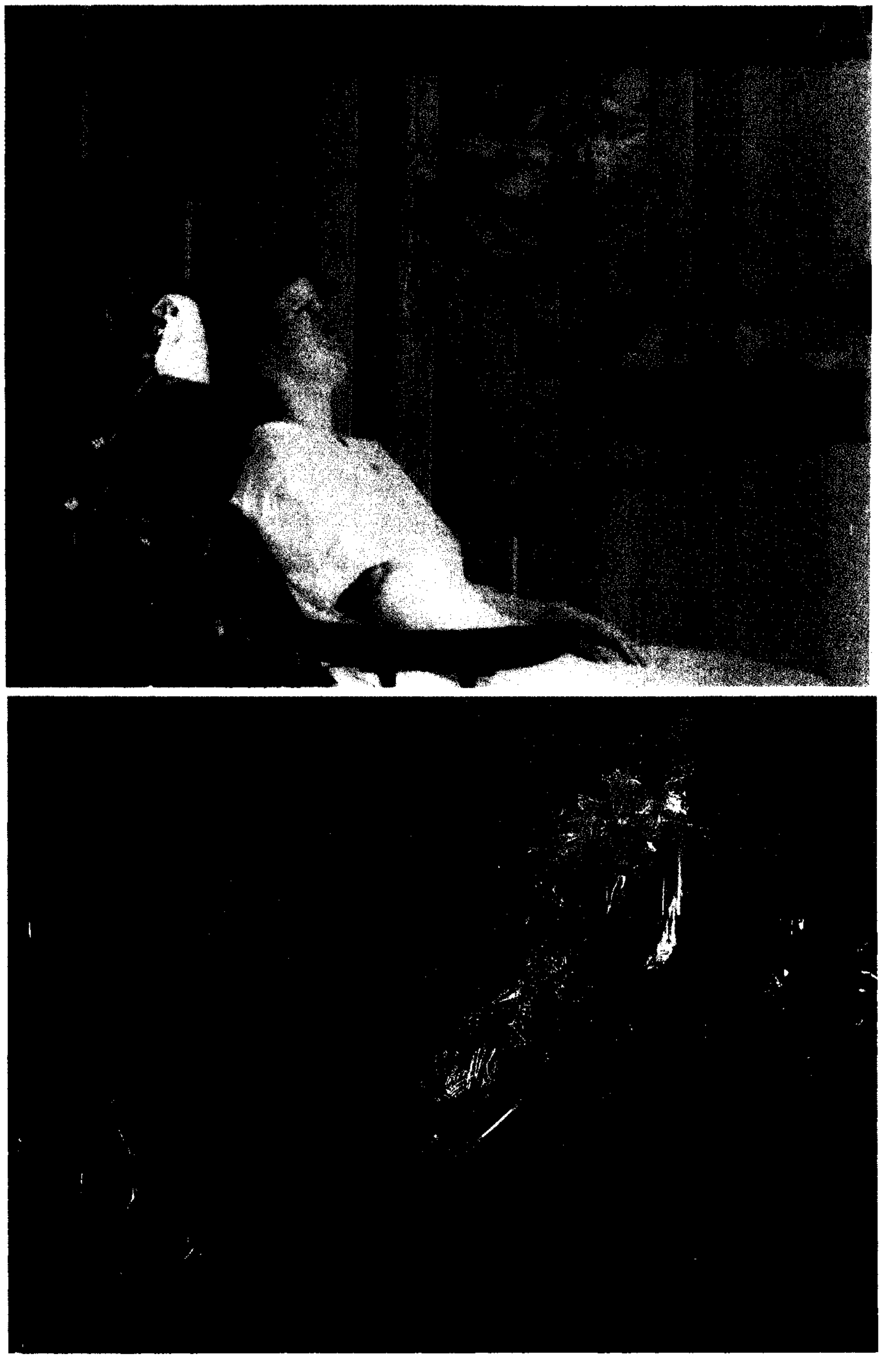
Figures 6.1 C, D. Association of dental full mouth x-rays and meningioma by years before reference date compared with recall accuracy of full mouth x-rays by time since reference date. The sliding window panel C shows the possibility that cases forgot more full mouth x-ray visits than controls, since the odds ratio falls below 1.0 for the earliest time periods. We hypothesize (depicted by the **?**) in panel D that both cases and controls also tended to forget more full mouth visits for the earliest time periods, although few records are available to test this theory.



Association of full mouth xrays with meningioma by year of exposure before reference date
C
Odds ratio of one full mouth xray
2.50
2.00
1.50
1.00
0.50
0.00
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49
Years before reference date



Recall of full mouth xray compared to dental record by time since reference date
D
Recall of full mouth xrays
250%
200%
150%
100%
50%
0%
Controls
Cases
?
0 to 9
10 to 19
20 to 29
30 to 39
40 to 49
50 +
Years since reference date



Figures 6.2A, B. Early (circa 1930) and present day Seattle dental x-ray machine. In panel A, note the exposed high voltage wires and large unshielded x-ray tube. Compared to medical radiography, dental x-ray tubes and electrical sources are in close proximity to the human body and head, even into modern day (B). Courtesy of the Museum of History and Industry, Seattle, WA.

Table 6.1 Studies of the dose of ionizing radiation and subsequent risk for brain tumors.

Author (ref.)	Pub Year	Exposure	Outcome	time of exposure	"Fractions" or mean # radiation exposures	Mean dose to the brain (mGy)	Lowest brain dose (mGy)	Highest brain dose (mGy)	Mean age at first exposure (years)	Dose-response?	Spatial dose-response in brain?	Mean yrs follow-up after exp. (range)	**Excess Relative Risk/Sv***
Ron (9)	1988	cranial radiation	brain tumors	5 – 10 days	5	1500	700	7000	7.3	yes	yes	26 (0-33)	**3.2**
Karlsson (10)	1998	radiation tx (hemangioma)	CNS tumors	over days?	1.4	70	0	11500	0.9	yes	?	~35	**2.7**
Little (11)	1998	radiation tx (cancer)	brain tumors	over weeks?	not stated	6200	0	82700	6.0	yes	?	15.1(2-46)	**0.19**
Preston (13)	2003	atomic bomb blast	meningioma	seconds	1	270	5	>1000	27	yes	?	~45	**2.9**
Longstreth (7)	2004	dental full mouth x-rays	meningioma	minutes-yrs	~2 FMX	~5	0	50*****	~28	no	no	~25(0-61)	**~10-20****
Preston-Martin (5,13,14)	1980, 1983, 1989	dental full mouth x-rays	meningioma	minutes-yrs	~ 2 FMX	?	?	?	?	?	yes	?	**?**

Legend

* excess relative risk (ERR) is the relative risk minus 1 assuming linear dose response relationship

** this is a rough estimate given about an average OR or 1.1 or 10% increased risk at 0.010 Gy full mouth xray exposure

*** exposure' for the Longstreth study in this table is for full mouth x-rays only, not bitewings, pan, ceph or cumulative exposure

***** doses estimated using dose to the sella turcica from chapter two

Table 6.2 Non-causal and causal explanations of why the excess relative risk is so large for dental radiography.

Type of error	Explanation for	Explanation against	Estimated Probability
Non-causal			
Residual confounding	Although education was controlled, there may still be residual confounding by other other socio-economic factors, since dental x-ray utilization is strongly associated with income/education. The error would falsely elevate the OR, and ERR, when it is actually 1.0 and 0.	Education is minimally associated with meningioma; although this effect is likely, it is unlikely that better control will reduce the OR to 1.0	likely
Differential misclassification	Recall bias - cases recall more full mouth xrays than controls in the critical time period 10 to 30 years before reference date, falsely elevating the OR and ERR.	Validation study shows no bias in the critical time period, but few controls were exposed to FMX in the earliest time period (>20 years), creating statistical uncertainty	unlikely
Non-differential misclassification	Because FMX is so imprecisely recalled, non-differential misclassification falsely elevates rather than diminishes the OR.	This type of misclassification only rarely occurs.	unlikely
Chance	Multiple tests and analyses were performed, and only the significant ones were listed, while the real OR is 1.0 and ERR is 0.	Analyses were decided a priori ; Three studies have shown similar effects.	unlikely
Causal			
Non-differential misclassification	Both cases and controls forgot exposures to dental radiographs, especially FMX and earliest exposures which were the highest dose	Evidence for this 'forgetting' is listed in figure 6.1.	likely
New mechanism	Dental ionizing radiation interacts with the dental non-ionizing radiation to potentiate the carcinogenic effects on meningeal cells, increasing the ERR.	Only equivocal evidence currently exists from in vitro and animal models	possible
New mechanism	Dental ionizing radiation affects the thyroid gland to augment growth of meningioma cells, increasing the ERR.	Theoretical argument based on mechanisms with other outcomes (LBW) and animal models	possible
Differential misclassification	The cases had radiographs taken with higher doses than the controls, thereby increasing the dose in cases and creating a larger differential dose between cases and controls, elevating the ERR more than it should	Not investigated yet.	possible
Non-differential misclassification	Dental dosimetry estimates are too low, thus leading to a higher ERR than actual.	Estimates are similar to other published point estimates except higher in 1950's-60's	unlikely

Legend:
OR = Odds ratio, closely approximating the relative risk in this case-control study
ERR= Excess relative risk, or relative risk minus 1.0
probability of explanation listed on 3 point scale of likely, possible, and unlikely .

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Appendix A.1

Survey of X-ray Practices in the Dental Office - Dentists

We are investigating the usual x-ray practices of dentists in our region and would like you to answer a few questions. This should take no more than 4-5 minutes of your time, and will be completely confidential, since we will not use any unique identifiers linked to you on this form. ***The aim of this survey is not to evaluate the quality or performance of individuals, but instead to make some general estimates of the usual x-ray practices within dentistry.***

_______ **1. What is your gender?** (1=Male; 2=Female)

_______ **2. What is your age?**

_______ **3. How many years have you been practicing as a dentist?**

. . . .

Please answer the following questions based on your ***current*** *x-ray practices.*

_______ **4. Are full mouth x-rays (FMX) taken:** 1=on the premises; 2=elsewhere; 3=not at all **in this office?**

if you answered '1'... a. In general, how many total x-rays are taken for FMX on an adult in this office? _______ (DK= don't know)
b. How many of those are bitewing x-rays (BWX)? _______
c. How many of those are periapical x-rays (PA's)? _______

_______ **5. Are bitewing x-rays (BWX) taken:** 1=on the premises; 2=elsewhere; 3=not at all **in this office?**

if you answered '1'... a. In general, how many total x-rays are taken for BWX on a person *age 13 and older* in this office? _______
b. In general, how many total x-rays are taken for BWX on a person *younger than 13* in this office? _______

_______ **6. Are panoramic x-rays (Pano's) taken:** 1=on the premises; 2=elsewhere; 3=not at all **in this office?**

_______ **7. Are cephalometric x-rays (Ceph's) taken:** 1=on the premises; 2=elsewhere; 3=not at all **in this office?**

The following questions address the topic of ***retakes*** *of dental x-rays. To ensure high quality films, x-rays may be retaken for for a variety of reasons varying from "cone-cuts", to needing a different angle, to problems with film developing. If you answered "1=on the premises" to any of the questions above, please answer the corresponding questions below.*

Specify: number or DK = don't know or NA = not applicable

_______ **4d. If 10 sets of FMX were taken in this office, how many *individual* x-rays total typically might be retaken for any reason?**

_______ **5c. If 20 sets of BWX were taken in this office, how many *individual* x-rays total typically might be retaken for any reason?**

_______ **6a. If 20 panoramic x-rays were taken in this office, how many Pano's total might need to be retaken for any reason?**

_______ **7a. If 20 cephalometric x-rays were taken in this office, how many Ceph's total might need to be retaken for any reason?**

One's x-ray practices may change over time. We ask that you answer the following questions regarding the ***past*** *if they apply.*

(Please circle)

8. Do you think your retake rates for FMX 10 years ago were more / less / the same **than your present day practice?**
a. How about for 20 years ago? more / less / the same

9. Do you think your retake rates for BWX 10 years ago were more / less / the same **than your present day practice?**
a. How about for 20 years ago? more / less / the same

10. Do you think your retake rates for PANO's 10 years ago were more / less / the same **than your present day practice?**
a. How about for 20 years ago? more / less / the same

11. Do you think your retake rates for CEPHS's 10 years ago were more / less / the same **than your present day practice?**
a. How about for 20 years ago? more / less / the same

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_______ **Subject #** _______ **Office #** __ 2 __ **MOMA subject (1=yes; 2=no)** ___/___/___ **SURVEY DATE**
__ 6 __ **INTERVIEW FORMAT**

Appendix A.2

Survey of X-ray Practices in the Dental Office - Endodontists

We are investigating the usual x-ray practices of endodontists in our region and would like you to answer a few questions. This should take no more than 4-5 minutes of your time, and will be completely confidential, since we will not use any unique identifiers linked to you on this form. ***The aim of this survey is <u>not</u> to evaluate the quality or performance of individuals, but to make some general estimates about usual x-ray practices within dentistry.***

_______ **1. What is your gender?** (1=Male; 2=Female)

_______ **2. What is your age?**

_______ **3. How many years have you been practicing as an endodontist?**

. . . .

*<u>Please answer the following questions based on your **current** x-ray practices.</u>*

_______ **4. What kind of x-rays are usually taken in this office?** (1=Standard x-rays; 2=Digital x-rays; 3=Both)

If you answered '3'... a. What percent of the total x-rays taken are standard? _______ %

b. What percent of the total x-rays taken are digital? _______ %

5. In general, how many total x-rays usually are taken for the following types of root canals in this office?

(Fill one column only)

	Using Standard only	Using Digital only	Using both Standard / Digital
a. One (1) canal root canal?	_______	_______	_______/_______
b. Two (2) canal root canal?	_______	_______	_______/_______
c. Three (3) canal root canal?	_______	_______	_______/_______
d. Four (4) canal root canal?	_______	_______	_______/_______

The following questions address the topic of retakes of dental x-rays. To ensure high quality films, x-rays may be retaken for a variety of reasons varying from "cone-cuts", to needing a different angle, to problems with film developing. Please answer the following questions related to question #5 above.

In your estimation...

_______ **6. If 10 *one canal* root canal procedures were performed in this office, how many *individual* x-rays <u>total</u> might need to be retaken for any reason?**

_______ **7. If 10 *two canal* root canal procedures were performed in this office, how many *individual* x-rays <u>total</u> might need to be retaken for any reason?**

_______ **8. If 10 *three canal* root canal procedures were performed in this office, how many *individua* l x-rays <u>total</u> might need to be retaken for any reason?**

_______ **9. If 10 *four canal* root canal procedures were performed in this office, how many *individual* x-rays <u>total</u> might need to be retaken for any reason?**

*<u>One's x-ray practices may change over time. We ask that you answer the following questions regarding the **past** if they apply.</u>*

(Please circle)

Do you think your retake rates...

10. **for 1 or 2 canal root canal procedures 10 years ago were** more / less / the same **than your present day practice?**

a. How about for 20 years ago? more / less / the same

11. **for 3 to 4 canal root canal procedures 10 years ago were** more / less / the same **than your present day practice?**

a. How about for 20 years ago? more / less / the same

Thank you for your time and participation.

<u>For internal use only</u> E - DDS part 1 v 4.3
_______ Subject ID # _______ Office # _______ MOMA subject (1=yes; 2=no) _______ / _______ / _______ *SURVEY DATE*
__6__ INTERVIEW FORMAT

Appendix A.3

Survey of X-ray Practices in the Dental Office - Orthodontists

We are investigating the usual x-ray practices of orthodontists in our region and would like you to answer a few questions. This should take no more than 4-5 minutes of your time, and will be completely confidential, since we will not use any unique identifiers linked to you on this form. ***The aim of this survey is <u>not</u> to evaluate the quality or performance of individuals, but instead to make some general estimates of the usual x-ray practices within dentistry.***

_______ **1. What is your gender?** (1=Male; 2=Female)

_______ **2. What is your age?**

_______ **3. How many years have you been practicing as an orthodontist?**

. . . .

*<u>Please answer the following questions based on your **current** x-ray practices.</u>*

_______ **4. Are full mouth x-rays (FMX) taken:** 1=on the premises; 2=elsewhere; 3=not at all **in this office?**

if you answered '1'... a. In general, how many total x-rays are taken for FMX on an adult in this office? _______ (DK= don't know)
b. How many of those are bitewing x-rays (BWX)? _______
c. How many of those are periapical x-rays (PA's)? _______

_______ **5. Are bitewing x-rays (BWX) taken:** 1=on the premises; 2=elsewhere; 3=not at all **in this office?**

if you answered '1'... a. In general, how many total x-rays are taken for BWX on a person *age 13 and older* in this office? _______
b. In general, how many total x-rays are taken for BWX on a person *younger than 13* in this office? _______

_______ **6. Are panoramic x-rays (Pano's) taken:** 1=on the premises; 2=elsewhere; 3=not at all **in this office?**

_______ **7. Are cephalometric x-rays (Ceph's) taken:** 1=on the premises; 2=elsewhere; 3=not at all **in this office?**

*The following questions address the topic of **retakes** of dental x-rays. To ensure high quality films, x-rays may be retaken for for a variety of reasons varying from "cone-cuts", to needing a different angle, to problems with film developing. If you answered "1=on the premises" to any of the questions above, please answer the corresponding questions below.*

Specify: <u>number</u> or <u>DK</u> = don't know or <u>NA</u> = not applicable

_______ **4d. If 10 sets of FMX were taken in this office, how many *individual* x-rays <u>total</u> typically might be retaken for any reason?**

_______ **5c. If 20 sets of BWX were taken in this office, how many *individual* x-rays <u>total</u> typically might be retaken for any reason?**

_______ **6a. If 20 panoramic x-rays were taken in this office, how many Pano's <u>total</u> might need to be retaken for any reason?**

_______ **7a. If 20 cephalometric x-rays were taken in this office, how many Ceph's <u>total</u> might need to be retaken for any reason?**

*<u>X-ray practices may change over time. We ask that you answer the following questions regarding your **past** practices if they apply.</u>*

(Please circle)

8. **Do you think your retake rates for FMX 10 years ago were** more / less / the same **than your present day practice?**
   a. How about for 20 years ago? more / less / the same

9. **Do you think your retake rates for BWX 10 years ago were** more / less / the same **than your present day practice?**
   a. How about for 20 years ago? more / less / the same

10. **Do you think your retake rates for PANO's 10 years ago were** more / less / the same **than your present day practice?**
    a. How about for 20 years ago? more / less / the same

11. **Do you think your retake rates for Ceph's 10 years ago were** more / less / the same **than your present day practice?**
    a. How about for 20 years ago? more / less / the same

Thank you for your time and participation.

For internal use only O - DDS part 1
Subject # ___ Office # ___ MOMA subject ... SURVEY DATE
6 INTERVIEW FORMAT

Appendix A.4

Survey of Dental X-ray Exposure, Record keeping, Storage and Billing - General Dentists

We are investigating the usual x-ray practices of dentists in our region for specific dental procedures. Please take a little time to look over this chart and estimate how many radiographs you would usually expose, record, store and bill for a patient for the procedures listed below. For example, dentists commonly take 4 total PA's for an anterior 1 canal root canal, but do not bill for all 4 x-rays or write down that 4 x-rays were taken. These estimates should apply to the time period of 1990 to 2002. We are most interested in the number of films exposed, and the number recorded in the chart.

*Write down "DK" if you don't know.

Procedure	Estimated number of procedures done per day / week / month	Radiographs ***Exposed*** on patient			Radiographs ***Stored*** in chart / computer			Radiographs ***Recorded*** in chart			Radiographs ***Billed*** to insurance or patient		
		PA's	BWX	PANO	PA's	BWX	PANO	PA's	BWX	PANO	PA's	BWX	PANO
Examples:													
Post and core	*4 per month*	*1*			*1*			*0*			*0*		
1 canal root canal	*1 per week*	*4*			*2*			*2*			*1*		
Initial Exam													
Recall Exam													
Evaluation of painful tooth													
1 canal root canal													
3 canal root canal													
Anterior post and core													
Single Tooth Extraction													
Extract 4 Third Molars													
Crown prep													
Crown seat													
4 BW X-rays													

For internal use only vers 5.0
_______ Subject ID # ___/___/___ Survey Date

Appendix B.1

SCHOOL OF DENTISTRY
DEPARTMENT OF ORAL MEDICINE

UNIVERSITY OF WASHINGTON

« Date»

« DDSname»
« DDSaddress1»
« DDSaddress2»

RE: « subjectitle» « subjectfirstname» « Subjectlastname» Dates seen: « Datesseen»
Date of Birth: « Date»

Dear « DDSname» :

We are members of a group of investigators at the University of Washington who are studying, with support from the National Institutes of Health, potential risk factors for meningioma, a relatively common type of intracranial tumor. As part of this investigation, we are studying two groups of people: those who have been diagnosed with a meningioma, and others randomly selected from King, Pierce and Snohomish Counties. One of the possible risk factors suggested by earlier studies is low dose ionizing radiation. One of the several sources of such radiation to the head and neck are dental radiographs, which is why we are contacting you to request your help.

« subjectitle» « subjectfirstname» « Subjectlastname» was interviewed as part of this study and indicated that « Gender1» has been seen by « PreviousDDS» from « Datesseen» . « subjectitle» « Subjectlastname» has given us permission to review « Gender2» dental records. A copy of « Gender2» consent will be enclosed with the next mailing.

We ask your assistance in obtaining information about the dental treatment that was performed on this patient. **We will be sending you a short form within 6 - 9 days**. The first part concerns the dates that this person was seen in your office and the procedures completed. This information can be compiled from any and all records, and can be done by you or an assistant. The second and third parts contain questions about dental radiographs and should be completed by you. All the information you provide will be kept strictly confidential, as provided by law. No study participant nor dentist will be identified to anyone outside the research staff, and all information collected will be used for research purposes only.

The effect of low dose radiation on the risk of developing this type of tumor has been debated for years. We remain skeptical of these effects, however, because no other study has gone the extra step of using actual medical and dental records. Because of the design and larger size, our current study has a better chance than the previous investigations of answering this important question. Your help will greatly aid us in getting the most accurate information possible. If you have any questions about the study or this request, please contact one of us or Sarah Velde, the study coordinator, at (206) 731-3654. Thank you for your assistance.

Sincerely,

Mark Drangsholt MS

Mark Drangsholt, DDS, MPH
Department of Oral Medicine, School of Dentistry
University of Washington, Box 356370
Seattle, WA 98195
(206) 543-2034

W.T. Longstreth Jr., MD, MPH
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Appendix B.2

SCHOOL OF DENTISTRY
DEPARTMENT OF ORAL MEDICINE

UNIVERSITY OF WASHINGTON

« DateSecondletter»

« DDSname»
« DDSaddress1»
« DDSaddress2»

RE: « subjectitle» « subjectfirstname» « Subjectlastname» Dates seen: « Datesseen»

Dear « DDSname» :

We sent you a letter within the last week that introduced our study about the potential risk factors for an intracranial tumor called a meningioma. We are contacting you again to obtain information about the dental treatment that was performed on one of your patients.

« subjectitle» « subjectfirstname» « Subjectlastname» was interviewed as part of this study and indicated that « Gender1» has been seen by « PreviousDDS» from « Datesseen» . « subjectitle» « Subjectlastname» has given us permission to review « Gender2» dental records. A copy of « Gender2» consent is enclosed.

Enclosed is the form to complete. The first part concerns the dates that this person was seen in your office and the procedures completed. This information can be compiled from any and all records, and can be done by you or an assistant. Our previous respondents have indicated that completing this section has taken anywhere from 5 to 15 minutes. If you wish, you may send us a photocopy of their records either in addition to or in place of this form. The second part contains questions about dental radiographs and should be completed by you. This portion usually takes about 5 to 10 minutes for dentists to complete. All the information you provide will be kept strictly confidential, as provided by law. No study participant nor dentist will be identified to anyone outside the research staff, and all information collected will be used for research purposes only.

The effect of low dose radiation on the risk of developing this type of tumor has been debated for years. We remain skeptical of these effects, however, because no other study has gone the extra step of using actual medical and dental records. Because of the design and large size, our current study has a better chance than the previous investigations of answering this important question. Your help will greatly aid us in getting the most accurate information possible. If you have any questions about the study or this request, please contact one of us or Jo-Ann Gehrels, the study coordinator, at (206) 731-3654. Thank you for your assistance.

Sincerely,

Mark Drangsholt, DDS, MPH
Department of Oral Medicine, School of Dentistry
University of Washington, Box 356370
Seattle, WA 98195

W.T. Longstreth Jr., MD, MPH
Department of Neurology, School of Medicine
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Appendix B.3

SCHOOL OF DENTISTRY
DEPARTMENT OF ORAL MEDICINE

UNIVERSITY OF WASHINGTON

« DateThirdletter»

« DDSname»
« DDSaddress1»
« DDSaddress2»

RE: « Subject» (« ID»), Dates seen: « Datesseen»

Dear « DDSname» :

We sent you a letter and a form to complete about three weeks ago in regards to our study about the potential risk factors for an intracranial tumor called a meningioma. As of today we have not received your completed forms.

Our research group has undertaken this study to help resolve a long-standing question about the effects of low level radiation from all sources on this risk of these tumors. We believe that, with your help, we have a good chance of resolving this important question.

Enclosed is another, identical form to complete, in case you have misplaced the first one. The first part concerns the dates that this person was seen in your office and the procedures completed. This information can be compiled from any and all records, and can be done by you or an assistant. Our previous respondents have indicated that completing this section has taken anywhere from 5 to 15 minutes. If you wish, you may send us a photocopy of their records either in addition to or in place of this form. The second part contains questions about dental radiographs and should be completed by you. This portion usually takes about 5 to 10 minutes for dentists to complete. All the information you provide will be kept strictly confidential, as provided by law. No study participant nor dentist will be identified to anyone outside the research staff, and all information collected will be used for research purposes only.

If you have any questions about the study or this request, please contact one of us or Jo-Ann Gehrels, the study coordinator, collect at (206) 731-3654. Your cooperation is greatly appreciated. We thank you for your assistance.

Sincerely,

Mark Drangsholt, DDS, MPH
Department of Oral Medicine, School of Dentistry
University of Washington, Box 356370

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Appendix B.4

SCHOOL OF DENTISTRY
DEPARTMENT OF ORAL MEDICINE

UNIVERSITY OF
WASHINGTON

« DateFourthLetter»

« DDSname»
« DDSaddress1»
« DDSaddress2»

RE: « subjectitle» « subjectfirstname» « Subjectlastname» Dates seen: « Datesseen»

Dear « DDSname» :

We previously sent you a letter and form to complete on « DateThirdletter» in regards to our study about the potential risk factors for an intracranial tumor called a meningioma. One of our subjects, « subjectitle» « subjectfirstname» « Subjectlastname» , indicated to us that « Gender1» had received dental care from you approximately during the dates listed above. As of today, we have not received a response from you.

Our research group has undertaken this study to help resolve a long-standing question about the effects of low level radiation from all sources on the risk of these tumors. We believe that, with your help, we have a good chance of resolving this important question.

Because obtaining these records are critical to the success of our study, **we would like to offer to help you by abstracting or copying the dental record for this subject in your office.** Our previous experience with these in-office abstracting has shown that it takes about 15 minutes to one hour for us to complete this task. All that we ask of you is to provide any or all parts of the dental chart for this person, and a place for us to sit and write for the time required to complete this task. Our research staff person, Yvonne Griffin, is both a registered nurse and former dental assistant who is familiar with dental terminology. If you wish, you could still send us a photocopy of their records either in addition to or in place of this form, or provide us one when we come by your office.

We would like to assure you again that all the information you provide will be kept strictly confidential, as provided by law. No study participant nor dentist will be identified to anyone outside the research staff, and all information collected will be used for research purposes only.

One of us will call you in the next week to set up a convenient time to come by your office.

If you have any questions about the study or this request, please contact one of us or Jo-Ann Gehrels, the study coordinator, at (206) 731-3654.

Your cooperation is greatly appreciated. We thank you for your assistance.

Sincerely,

Mark Drangsholt, DDS, MPH
Department of Oral Medicine, School of Dentistry
University of Washington, Box 356370
(206) 543-2034

W.T. Longstreth Jr., MD, MPH
Department of Neurology, School of Medicine
University of Washington, Box 359775

B316 Health Sciences Center Box 356370 Seattle, Washington 98195-6370
direct 206.543.6501 FAX 206.685.8412

Appendix B.5

UNIVERSITY OF WASHINGTON

« DateThankyou»

« DDSname»
« DDSaddress1»
« DDSaddress2»

RE: « subjectitle» « subjectfirstname» « Subjectlastname»

Dear « DDSname» :

We would like to thank you for participating in the Meningioma Research Study. We have received this subjects' complete dental records from your office. Your careful consideration of our request and thorough response has been especially valuable in our research. Because of your response, and the response of other dentists, our ability to gather records has been better than expected.

This study will continue through June, 2000. We hope that we may call upon you again if, by chance, another subject in our study indicates that he or she was seen by you.

If you have any questions about the study, please contact one of us or Jo-Ann Gehrels, the study coordinator, at (206) 731-3654.

Sincerely,

Mark Drangsholt, DDS, MPH
Department of Oral Medicine, School of Dentistry
University of Washington, Box 356370

W.T. Longstreth Jr., MD, MPH
Department of Neurology, School of Medicine
University of Washington, Box 359775

Seattle, Washington 98195

VITA

MARK THOMAS DRANGSHOLT

Birthdate: December 8, 1957

Education

University of Washington	1976-1981, March 1981	B.A. (Zoology)
University of Washington	1980-1984, June 1984	D.D.S. (with Honors)
Michael Reese Hospital and Medical Center	1984-1985, July 1985	Certificate (General Practice)
University of Washington	1987-1992, March 1992	M.P.H. (Epidemiology)
University of Washington	1989-1995, June 1995	Certificate (Oral Medicine)
University of Washington	1995-1996, March 1996	Ph.C. (Epidemiology)
University of Washington	1997-2004, August 2004	Ph.D. (Epidemiology)

Honors

Dental School Honors (Undergraduate)

Omicron Kappa Upsilon Scholarship for Highest Academic Standing in Class, 1st of 100 students (1982)
National Dean's List (1981-1982, 1982-1983)
Omicron Kappa Upsilon, Recognition of Scholarship (1981, 1982, 1983)
Washington State Dental Association Table Clinic Award, 2nd place (1982)
Certificate for Recognition of Governance (Class President, 1982-1983)
Certificate for Recognition of Governance (Student Council President, 1983-1984)
University of Washington Dental Alumni Table Clinic Award (1982)
University of Washington Representative to the National Student Table Clinic Competition (1983)
Honor Prosthodontics (1983-4)

Dental School Graduation Honors (1984)

Awarded membership in Omicron Kappa Upsilon
Dennis P. Duskin Inspirational Award, awarded by majority vote of the graduating class
Honor Graduate in Dentistry
Pierre Fauchard Academy Senior Student Award
Quintessence Award for Clinical Achievement in Restorative Dentistry

Post-Doctoral Honors

Outstanding Instructor - School of Dentistry, Class of 1991 (1990).
American Association for Dental Research - Northwest Region - Student Research Prize (1993).
Warren G. Magnuson Scholars Award - Graduate Student with Outstanding Potential - School of Dentistry recipient (1994).
2nd place, Poster presentation competition (2nd of 101), Society for Epidemiologic Research (2002).

Publications

Peer-reviewed Scientific Publications (29)

1. Chen, A.C.N., Drangsholt, M.T., Dworkin, S.F., and Clark, D.: Micro-computer analysis of cortical power spectrum: calibration and correlates of behavioral artifacts. Biol Psych 16:181-196, 1983.

Peer-reviewed Scientific Publications (29, cont.)

2. Chen, A.C.N., Dworkin, S.F., and Drangsholt, M.T.: Cortical Power spectral analysis of acute pathological pain. Intern J Neuroscience 18:269-278, 1983.

3. Longstreth, W.T. Jr., Dennis, L.K., McGuire, V.M., Drangsholt, M.T., and Koepsell, T.D.: Epidemiology of Intracranial Meningioma. Cancer 72:639-648, 1993.

4. Tong, D.C., Rioux, K., Drangsholt, M.T., Beirne, O.R.: A review of survival rates for implants placed in grafted maxillary sinuses using meta-analysis. Int J Oral Maxillofac Implants 13(2): 175-182, March 1998.

5. Drangsholt, M.T.: A new causal model of dental diseases associated with endocarditis. Annals of Periodontology 3(1): 184-196, July 1998.

6. Drangsholt, M.T. and LeResche, L.: Temporomandibular Disorder Pain. In: Epidemiology of Pain I. Crombie (ed.), IASP Press, Seattle, WA, 1999, pp. 203 –234.

7. Drangsholt, M.T.: Commentary: Investigation of Bacteremia following Orthodontic Debanding. Angle Orthodont 70(1): 15, 2000.

8. Hujoel, P.P., Drangsholt, M.T., Spiekerman, C. and DeRouen, T.A.: Periodontal Disease and Coronary Heart Disease Risk. JAMA 284(11): 1406-10, Sep. 20, 2000.

9. LeResche, L. and Drangsholt, M.T.: Temporomandibular disorders. In: Women and Health M.B. Goldman and M.C. Hatch (eds.), Academic Press, San Diego, 2000, pp.1120-1128

10. Hujoel, P.P., Drangsholt, M.T., Spiekerman, C. and DeRouen, T.A.: Examining the link between coronary heart disease and the elimination of chronic dental infections. J Am Dent Assoc 132(7):883-9, July 2001.

11. Drangsholt, M.T.: Preface to Evidence-Based Case Conference. J Evid Based Dent Prac 1(1):38-40, 2001.

12. Drangsholt, M.T. and Truelove, E.L.: Trigeminal Neuralgia mistaken as Temporomandibular disorder. J Evid Based Dent Prac 1(1):41-50, 2001.

13. Drangsholt, M.T., Truelove, E.L., Morton, T.A., and Epstein, J.B.: A man with a 30-year history of oral lesions. J Evid Based Dent Prac 1(2):85-96, 2001.

14. Martin, M.D., Drangsholt, M.T., and Futran, N.D.: A 74-year-old woman with a painful gingival lesion. J Evid Based Dent Prac 1(3):85-96, 2001.

15. John, M.T., Hirsch, C., Drangsholt, M.T. and Mancl, L.A.: Overbite and Overjet are not related to Self-Report of Temporomandibular Disorders Symptoms. J Dent Res 81(3):164-167, 2002.

16. Hujoel, P.P., Drangsholt, M.T., Spiekerman, C., and DeRouen, T. A.: Pre-existing Cardiovascular Disease and Peridontitis: A Follow-up Study. J Dent Res 81(3):186-91, 2002.

17. John, M.T., Frank, H., Lobbezoo, F., Drangsholt, M.T. and Dette, K.E.: No association between incisal tooth wear and temporomandibular disorders. J Prosthet Dent 87(2):197-203, Feb. 2002.

18. Hancock, P., Drangsholt, M.T. and Truelove, E.L.: A 31 year old women with jaw deviation and pain I. J Evid Based Dent Prac 2(2), 168-174, June 2002.

Peer-reviewed Scientific Publications (29, cont.)

19. Huang, G.J., LeResche, L., Critchlow, C.W., Martin, M.D. and Drangsholt, M.T.: Risk factors for painful subgroups of Temporomandibular Disorders (TMD). J.Dent Res 81(4):284-288, 2002.

20. Drangsholt, M.T., Hancock, P., and Truelove, E.L.: A 31 year old woman with jaw deviation and pain II. J Evid Based Dent Prac 2(3): Sept 2002, 254-257.

21. Hujoel, P.P., Drangsholt, M.T., Spiekerman, C., and DeRouen, T. A.: Cause or coincidence? Periodontitis-systemic disease associations in the presence of smoking. Perio 2000, 30: 51-60, 2002.

22. Hujoel, P.P., Drangsholt, M.T., Spiekerman, C. and Weiss, N.S.: "An Exploration of the Periodontitis-Cancer Association". Ann Epidemiol. 2003 May;13(5):312-6.

23. Fischer, D., Govin, G, Jurkovic, D, and Drangsholt, M. A 70-year-old woman with dementia and multiple carious lesions. J Evid Based Dent Prac,3(1) March 2003.

24. Dworkin S.F. and Drangsholt, M. Clinical Trials in TMD. In: Interactive Textbook for Symptom Research: Methods and Opportunities, 2003, Max, M and Lynn, J, editors.

25. Martin, M.D., Drangsholt, M.T. and Broughton, S.: Oral lichen planus and dental metals: a case-control study. Contact Dermatitis, 2003, 48: 331-336.

26. Drangsholt, M. Schubert, MM, Ritchie, CS. A 29 year old asplenic male with overwhelming sepsis after tooth extractions and postoperative infection. . J Evid Based Dent Prac 3(2): Sept 2003.

27. Longstreth Jr WT, Phillips LE, Drangsholt M, Koepsell TD, Custer BS, Gehrels JA, van Belle G. Dental x-rays and the risk of intracranial meningioma: a population-based case-control study. Cancer 2004 Mar 1; (100)5:1026-1034.

28. Lobbezoo, F., Peck, C.C., Drangsholt, M., Sato, H., Kopp, S. and Svensson, P.: New insights into the Pathology and Diagnosis of the TMJ. J Orofacial Pain, 2004, 18(3).

29. Drangsholt MT. Evidence-based case conference: taking stock after 3 years. . J Evid Based Dent Prac 4(2), June, 2004.

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1. Drangsholt, M.T., LeResche, L., Ramsay, D.S., Herring, S., and Dworkin, S.F.: Comments on pediatric internal derangements of the TMJ. Am J Ortho Dentofacial Orthop 105(3), 38A-39A, 1994.

2. Drangsholt, M.T.: Current concepts review. Prophylactic use of antibiotics for procedures after total joint replacement. J Bone J Surg Am 80(9):1394-5, 1998.

3. Huang, G. and Drangsholt, M.T.: Stability of anterior open bite correction with MEAW. Am J Orthod Dentofacial Orthop 119(2):14A, Feb. 2001.

4. Hujoel, P.P., Drangsholt, M.T., Spiekerman, C., and DeRouen, T. A.: Periodontal Disease and Coronary Heart Disease Risk. JAMA 285(1): 1406-10, Jan. 3, 2001.

5. Hujoel, P.P., Drangsholt, M.T., Spiekerman, C., and DeRouen, T. A.: Heart of the Matter: Examining

the link between coronary heart disease and the elimination of chronic dental infections. J Am Dent Assoc 132(12):1648-52, Dec. 2001.

6. Hujoel, P.P., Drangsholt, M.T., Spiekerman, C., and DeRouen, T. A.: Pre-existing Cardiovascular Disease and Peridontitis: A Follow-up Study. J.Dent Res 81 (6), 372-373, 2002.

7. Hujoel, P.P. and Drangsholt, M. Radiation-induced thyroid dysfunction as a cause of low intelligence? BMJ, Jan 25, 2004.

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1. Pini-Prato, G. and Drangsholt, M.T.: Specific clinical diagnoses of TMJ disease did not demonstrate good agreement with diagnoses obtained by MRI. J Evid Based Dent Prac 1(3), 194 to 195, Dec 2001.

2. Binnie W.H., and Drangsholt, M.T.: Further study required to establish clinical guidelines for follow-up of patients with oral lichen planus. J Evid Based Dent Prac 1(3), 204 to 206, Dec 2001.

3. Drangsholt, M.T. and Hujoel, P.P.: Clinic patients with pain in their TMJ's usually have MRI-documented internal derangements. J Evid Based Dent Prac 2(1), March, 2002.

4. Drangsholt, M.T. Review provides insufficient evidence of efficacy of occlusal appliances in managing masticatory myalgia and arthralgia. J Evid Based Dent Prac 2(1), 26-27, March, 2002.

5. Ritchie, C.S. and Drangsholt, M.T.: Older adults who are edentate or with fewer numbers of teeth report significant oral impacts on daily life activities. J Evid Based Dent Prac 2(1), 58-59, March, 2002.

6. Ohrbach, R. and Drangsholt, M. Diagnostic devices may not provide additional diagnostic information for temporomandibular disorders. J Evid Based Dent Prac 2(2), 136-137, June, 2002.