PANORAMIC RADIOGRAPHS PRIOR TO COMPLETE DENTURE FABRICATION: A RETROSPECTIVE STUDY OF CLINICAL SIGNIFICANCE AND QUALITY ASSURANCE

by

Richard John Kratz

Hon. B.Sc., MSc., University of Guelph 2001
DDS., The University of Western Ontario, 2007

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES

(Craniofacial Science)

THE UNIVERSITY OF BRITISH COLUMBIA (Vancouver)

July 2015

© Richard John Kratz, 2015
Abstract

Purpose. There are concerns about the burden of ionizing radiation from radiographs, and consequently about the benefits of radiographic screening of edentulous mandibles. The primary aim of this retrospective study was to identify findings on digital panoramic radiographs of edentulous patients to determine how such findings impacted patient management prior to fabrication of complete dentures. Secondarily, a quality assurance assessment of the panoramic radiographs was completed by comparing two groups of students, 2\textsuperscript{nd} year Introduction to Prosthodontics (IPROS) and 3\textsuperscript{rd}/4\textsuperscript{th} year Integrated Clinical Care (ICC), regarding radiographic interpretations completed, positional errors detected, and radiographic interpretation errors made.

Methods. Two hundred digital panoramic radiographs taken on edentulous patients were identified from UBC Dentistry clinics between 2006-2012, of which 31 were excluded (clinical crowns or implants present, no digital panoramic present or analog image scanned in). An Oral and Maxillofacial Radiologist provided training and interpretation assistance, and randomly audited 20 panoramic radiographs for an observed proportion of agreement.

Results. There were 165 positive radiographic findings, of which 6 (3.6%) affected patient management. 301 positional errors were also identified, with 14 (8.3%) images free of error. There were significantly more (p<0.05) radiographic interpretations completed (p=0.00014) and positional errors correctly identified (p=0.002) in IPROS compared to ICC. No significant difference was observed for radiographic interpretation errors (p=0.059) between the two student groups.

Conclusion. The positive radiographic findings (PRFs) identified in the panoramic radiographs of edentulous patients in this study offered minimal benefits, with only 3.6% of
PRFs affecting patient management. We would therefore recommend that panoramic radiographic screening for this patient population be discontinued. The rate of positional errors for panoramic radiographs of edentulous patients was high, indicating a need for additional staff training to minimize errors and to maximize diagnostic benefits.
Preface

Dr. Richard Kratz conducted this retrospective research project under the direct supervision of Dr. Joanne Walton and Dr. David MacDonald. Committee members included Dr. J. Walton, Dr. D. MacDonald, Dr. M. MacEntee and Dr. C. Nguyen.

Dr. Kratz performed all data collection and analysis of the research data with the tutelage of Dr. MacDonald and meetings with Vivian Meng, a statistician consultant.

Although no direct contact with patients was required, to ensure proper protocol was adhered to and no violation of patient privacy was committed, ethics approval was obtained from the UBC Clinic Research Ethics Board (Certificate number: H12-03685) on Jan 23, 2013 and renewed in 2014.
# Table of Contents

Abstract ......................................................................................................................................................... ii
Preface............................................................................................................................................................. iv
Table of Contents .............................................................................................................................................. v
List of Tables ................................................................................................................................................... viii
List of Figures ................................................................................................................................................ x
List of Symbols ............................................................................................................................................. xi
List of Abbreviations .................................................................................................................................... xii
Acknowledgements ....................................................................................................................................... xiv
Dedication ....................................................................................................................................................... xvi

## Chapter 1: Introduction ............................................................................................................................... 1

1.1 Panoramic Radiographs .......................................................................................................................... 2

1.1.1 Advantages and Disadvantages of Panoramic Radiographs ......................................................... 3

1.1.2 Positional Errors Within Panoramic Radiographs .......................................................................... 5

1.1.3 Literature Review on Positional Errors Detected on Panoramic Radiographs ... 12

1.2 Digital Radiographs ............................................................................................................................... 14

1.2.1 Digital Terms ...................................................................................................................................... 16

1.2.2 Digital Receptors/Sensors ................................................................................................................ 17

1.2.3 Advantages of Digital Radiographs .............................................................................................. 22

1.3 Radiation Basics ................................................................................................................................... 24

1.3.1 Effective Dose ................................................................................................................................... 26

1.3.2 Biological Effects of Ionizing Radiation ......................................................................................... 28
1.3.3 Dosage of Panoramic Radiographs and Relative Risks of Biological Effects... 31
1.4 Arguments For and Against Screening Panoramic Radiographs......................... 32
  1.4.1 Arguments Against Screening Panoramic Radiographs.................................. 33
  1.4.2 Arguments For Screening Panoramic Radiographs........................................ 40
1.5 Rationale for this Research Project..................................................................... 45
1.6 Objectives and Hypotheses.................................................................................. 46

Chapter 2: Materials and Methods ............................................................................ 47
  2.1 Ethical Approval ................................................................................................. 47
  2.2 Parameters and Definitions Used....................................................................... 47
  2.3 Study Population............................................................................................... 50
    2.3.1 Exclusion Criteria ....................................................................................... 51
  2.4 Pilot Project and Data Collection....................................................................... 52
  2.5 Internal-rater Reliability..................................................................................... 53
  2.6 Post-Hoc Power Analysis .................................................................................. 53
  2.7 Data Analysis ..................................................................................................... 55
  2.8 Summary of Methods....................................................................................... 57

Chapter 3: Results ..................................................................................................... 58
  3.1 Demographics and Panoramic Radiograph Interpretations Completed for ICC and
IPROS Student Groups ............................................................................................. 58
  3.2 Positive Radiographic Findings (PRFs) and Effect on Treatment...................... 58
  3.3 Positional Errors............................................................................................... 62
  3.4 Inter-Rater Reliability - Experts........................................................................ 65
  3.5 Summary of Key Results.................................................................................... 66
Chapter 4: Discussion........................................................................................................ 67
  4.1  Positive Radiographic Findings (PRFs)................................................................. 67
    4.1.1  Yield of Positive Radiographic Findings....................................................... 67
    4.1.2  Effect on Treatment of Positive Radiographic Findings............................... 69
    4.1.3  Radiographic Interpretation Errors (RIEs).................................................... 72
  4.2  Positional Errors..................................................................................................... 73
    4.2.1  Positional Errors Detected: Comparison to the Literature............................ 73
    4.2.2  Positional Error Misidentifications (PEMs).................................................. 76
  4.3  Inter-Rater Reliability ............................................................................................ 79
  4.4  Statistical Significance of Results versus Clinical Significance......................... 80

Chapter 5: Conclusion..................................................................................................... 83
  5.1  Conclusions............................................................................................................ 83
  5.2  Significance of the Research............................................................................... 84
  5.3  Strengths and Limitations of the Research ......................................................... 87
  5.4  Future Research.................................................................................................... 88

Bibliography.................................................................................................................. 90
## List of Tables

Table 1: Manifestations of common positioning errors on panoramic radiographs\(^5, 21, 25, 33, 34\) 8

Table 2: Distribution of errors in panoramic radiographs ................................................. 12

Table 3: Relative distribution of positional errors detected on panoramic radiographs of edentulous jaws ................................................................................................. 13

Table 4: Terms used in digital radiology\(^5, 41, 43, 45\) ..................................................... 16

Table 5: Comparison of charge coupled device (CCD), photostimulable phosphor plates (PSP) and Film\(^5, 41, 45, 48, 49\) .......................................................... 21

Table 6: Comparison of effective doses of radiation from different sources ................. 32

Table 7: Reports on the distribution of positive radiographic findings in panoramic radiographs that assessed the impact on patient treatment .................................................. 36

Table 8: Examples of identified radiopaque (RO), radiolucent (RL), mixed (ML) and extragnathic (EN) lesions reported from panoramic radiographs\(^13, 15, 29, 67-69, 72, 73, 81, 84, 101\) ... 50

Table 9: Demographics and panoramic radiograph interpretations completed ................. 58

Table 10: Number of panoramic radiographs with positive radiographic findings (PRFs) identified by the experts and the effect on treatment as determined by students ............ 59

Table 11: Total expert positive radiographic findings (PRFs) for each student group and the effect on treatment as determined by the students ........................................................................ 60

Table 12: Number of radiographic interpretation errors (RIEs) made by students .......... 61

Table 13: False positive (FP) and false negative (FN) radiographic interpretation errors (RIEs) made in each radiographic category by students .......................................................... 62

Table 14: Number of panoramic radiographs with positional errors detected .......... 62
Table 15: Comparison of total positional errors detected by students versus the experts and total positional errors for each category................................................................. 63
Table 16: Comparison of positional errors detected between students and experts. .......... 64
Table 17: True positives, true negatives, false positives, and false negatives of positional errors detected across all categories................................................................. 64
Table 18: Positional error misidentifications (PEM) made by ICC and IPROS students ...... 65
Table 19: Summary of key results .................................................................................. 66
Table 20: Statistical versus clinical significance of key results...................................... 81
List of Figures

Figure 1: Edentulous patient with chin down. ................................................................. 9
Figure 2: Edentulous patient with chin up. ................................................................. 9
Figure 3: Edentulous patient with head rotated to the left. ........................................ 10
Figure 4: Edentulous patient with head shifted to the right. ..................................... 10
Figure 5: Edentulous patient slumped and head tilt slightly to the left ..................... 11
Figure 6: Electromagnetic spectrum. ............................................................... 25
Figure 7: The linear non-threshold (LNT) hypothesis\textsuperscript{52} . .......................... 30
Figure 8: Methods overview .................................................................................. 57
Figure 9A and 9B: Positional errors on panoramic radiographs can affect diagnosis. .... 75
List of Symbols

$\alpha = \text{alpha}$
$\beta = \text{beta}$
$\gamma = \text{gamma}$
$E = \text{energy}$
$h = \text{Planck’s constant}$
$c = \text{velocity of light}$
$\lambda = \text{wavelength}$
List of Abbreviations

avg - average
ADA – American Dental Association
ADC – analog-to-digital conversion
ALARA – as low as reasonably achievable
BW – bitewing
CCD – charged-coupled device
CCAA – calcified carotid artery atheroma
CI – confidence interval
CMOS – complementary metal oxide semiconductor
CRDP – complete removable dental prosthesis
CREB - Clinic Research Ethics Board
CT – computer tomography
DBI – dense bone island
DDx – differential diagnosis
E – energy
EHR – electronic health record
EN – extragnathic
FMS – full mouth series
FN – false negative
FP – false positive
ICC – Integrated Clinical Care
ICRP – International Commission on Radiological Protection
IO – idiopathic osteosclerosis
IPROS – Introduction to Prosthodontics
KCOT - keratocystic odontogenic tumour
kV – kilovolt
LN – lymph nodes
LNT – Linear non-threshold hypothesis
mA – milliamp
max – maxillary
mand - mandible
MGDG – medical gray scale diagnostic grade
ML – mixed lesion
NA – North America
NRPB – National Radiation Protection Board
OMFR – Oral Maxillofacial Radiologist
OMFS – Oral Maxillofacial Surgeon
PA – periapical
Pans – panoramic radiographs
PEM – positional error misidentification
PRF – positive radiographic finding
PSP – photostimulable storage phosphor plate/ photostimulable phosphor plates / photophosphorous storage plates
RIE – radiographic interpretation errors
RL - radiolucency
RO – radiopacity
RVG – RadioVisoGraphy
SD – standard deviation
S&S – signs and symptoms
SHL – stylohyoid ligament
Sv – Sieverts
TMJ – temporomandibular joint
TN – true negative
TP – true positive
SOS – satisfaction of search
Tx - treatment
UBC – University of British Columbia
USA – United States of America
UK – United Kingdom
yrs – years
vs – versus
Acknowledgements

I would like to express my sincerest gratitude to my supervisor Dr. Joanne Walton for her guidance, patience and timely constructive feedback. She always brought clarification to my endless questions and her leadership in our MSc committee meetings was an invaluable asset. Her continual pursuit of excellence is and will continue to be a source of inspiration throughout my career.

I thank Dr. David MacDonald for his early mornings and long hours in front of countless digital panoramic images providing me with exceptional radiographic interpretation guidance and counseling. This is a life-long skill that will enable me to better serve my future patients thanks to his outstanding expertise in the field of radiology.

To Dr. Michael MacEntee, I will take his curiosity and philosophical nature forward with me in life to enhance my ability to critically appraise the literature and fully appreciate the syntax of the written language. Learning to be as clear and concise is a valuable asset that is greatly appreciated by the Canadian Armed Forces.

I owe Dr. Caroline Nguyen my gratitude as well for her support and guidance as a member of my research committee who brought a unique and important perspective to the team with her work in Maxillofacial Prosthodontics and the detrimental effects of cancer and the importance of early detection and screening protocols for an at risk population.

I want to acknowledge Vivian Meng, a graduate statistician student, for her thorough Statistical Report and professional and timely feedback relating to the statistical analysis; as well as Dr. John Petkau, the Graduate 551 Consultation course director and supervisor who accepted the Thesis for review.
As well, I’d like to thank Nadine Bunting and Peter Hinz for their greatly appreciated behind the scenes support. They helped me gain a better understanding of the Planmeca ProMax panoramic radiograph machine and the electronic health record software used at UBC that helped immensely with data collection.

Last, but not least special thanks are owed to my parents, John and Martha Kratz, for their lifelong support and love. Among many things in life, they taught me how to achieve my goals by instilling in me a great work ethic with a “never quit” attitude. More importantly they taught me the value of family and friends and the importance of balance in life.
Dedication

This is dedicated to my precious wife, Kimberly Kratz. Not only is she my best friend, she is the love of my life. Without her constant support and encouragement, her selfless love and constant sacrifices that have allowed me to follow my dreams; none of my accomplishments would be possible, and none would mean as much without her at my side. As tiny as she may be, she is my rock! Thank you for being a part of my life and keeping my dreams alive.
Chapter 1: Introduction

The ALARA (as low as reasonably achievable) principle requires that exposure to ionizing radiation must be clinically justified and prescribed on an individual basis\textsuperscript{1-8}. The American Dental Association (ADA) updated their recommendations in 2004 for selection criteria that mimic European standards, stating that newly edentulous patients should have radiographs prescribed on an individual basis as indicated by clinical signs and symptoms (S&S)\textsuperscript{2,8-12}. Notwithstanding these current guidelines, there are advocates for the use of screening panoramic radiographs as part of conventional complete denture, or complete removable dental prosthesis (CRDP), treatment planning\textsuperscript{13}. They state that the benefits of identifying positive radiographic findings (PRFs), defined as any occult radiographic finding, outweigh the low risk for stochastic radiological effects, providing information to patients of potential hidden pathoses or anomalies that could affect the denture-bearing area or the patient’s health, while reducing the risk of potential law suits\textsuperscript{13,14}. However, what constitutes clinically significant PRFs remains open to interpretation and the effect the findings might have on treatment needs to be evaluated. It has been suggested that for PRFs to be clinically significant, they should lead to a “net benefit” for the patient and/or alter patient management, and not just satisfy the clinician’s curiosity\textsuperscript{3,15,16}. Radiological findings alone do not necessarily equate to clinical significance.

Moreover, dental graduates who go on to treat thousands of patients throughout their careers continue to prescribe radiographs according to personal routine\textsuperscript{9} that is most likely modeled on the teachings of the institution from which they graduated; so it’s important for educational institutions to adhere to evidence-based standards\textsuperscript{17-19}. 


To our knowledge, no work has been published regarding the clinical significance of screening panoramic radiograph findings since the introduction of digital radiography. It is possible that the ability to enhance digital radiographs could allow for improved detection of anomalies compared to the analog panoramic images assessed in previous studies. Additionally, clinical institutions such as the University of British Columbia (UBC) Faculty of Dentistry may benefit from additional quality assurance regarding the radiographic images produced and interpreted within its programs. If patients are being exposed to ionizing radiation, there is a responsibility on the institution to ensure that the images are properly made and interpreted. Panoramic radiographs on edentulous patients are notoriously difficult to take and this may affect the diagnostic quality of the images produced\textsuperscript{20, 21}.

1.1 Panoramic Radiographs

A few weeks after the discovery of x-rays in 1895, the first intraoral dental radiographs were taken by Otto Walkoff\textsuperscript{22, 23}. Shortly thereafter, due to some of the technical difficulties encountered with taking intraoral films, efforts were made to develop equipment that could extraorally radiograph the teeth, maxillary and mandibular jaws, and their surrounding structures (i.e. spine and skull)\textsuperscript{22}. After several decades of groundwork-laying efforts by people such as Numata in 1933 and Heckmann in 1939, Paatero and Hudson and colleagues, unaware of each other’s work, are given credit for providing the first pantograph for clinical use in the late 1940s and early 1950s\textsuperscript{5, 22, 24}.

Panoramic imaging or pantomography is a technique for producing a single tomographic image of the facial structures. This single panoramic image can be thought of as three images in one: left and right lateral images posterior to the canines, and a large periapical (PA) image.
anterior to the canines. The resultant panoramic image is essentially a series of curved image “slices” of the maxillary and mandibular arches and the midfacial structures created by the reciprocal movement of an x-ray source and an image receptor/sensor [rare earth films, charge-coupled device (CCD) or photostimulable phosphor plates (PSP)] moving in opposite directions. Since tomography refers to imaging by sections or sectioning, a panoramic radiograph can be considered a modified tomographic image. This produces an image at the fulcrum/central point on the receptor created by lead collimators in the shape of a slit, which limits the central x-ray to a narrow vertical beam creating an “image layer” or focal trough.$^{5,18}$ The focal trough is the area between the x-ray source and the receptor that will be reasonably well-defined and captured with minimal distortion. This is where the mandible (and teeth) should be properly positioned to ensure that a diagnostically adequate film is made. The focal trough can be adjusted on some machines to try and match the patient arch size and shape to improve accuracy.$^{5,25}$ To obtain optimal image definition, the speed of the receptor passing the collimator slit must equal the speed at which the x-ray beam passes through the object of interest within the focal trough.$^{5}$ The resulting geometric projection characteristics are similar for film and PSP and both must be “processed” in order to view the image. However, when the receptor is a CCD the image is instantly transmitted electronically to the computer screen in a continuous stream while the x-ray source and receptor are traveling around the patient.$^{5}$ Most panoramic machines now use a continuously moving rotation rather than multiple fixed locations.$^{5}$

1.1.1 Advantages and Disadvantages of Panoramic Radiographs

Panoramic images are most useful clinically for diagnostic concerns requiring broad coverage of the jaws.$^{22,26}$ Some suggested indications for the use of panoramic radiographs
include evaluation of trauma or suspected fractures when trismus due to radiation therapy or infection limits intraoral access, known or suspected large lesions, tooth development (especially during mixed dentition years), retained teeth or root tips in edentulous patients, temporomandibular joint (TMJ) pain, and developmental anomalies, such as unerupting third molars. The main factors influencing dentists to make panoramic radiographs were planning of oral surgery, facial trauma, periodontal disease, heavily restored dentition, new patient exams, and ownership of a panoramic unit within their office (i.e. ease of access). According to the Council on Dental Materials and Devices, the following are purported advantages of panoramic radiographs that make it so frequently used:

1) simple to perform
2) convenient to patient
3) useable for patients with intractable gagging problems
4) minimal time required (3-4 minutes)
5) those portions of the maxilla and mandible lying within the focal trough of the machine can be visualized clearly on a single film
6) patient dose is relatively low, but not negligible
7) useful as a visual aid in patient education.

However, despite the ease of use and numerous advantages to panoramic radiographs, there are several drawbacks. From a diagnostic standpoint, due to unequal magnification, lack of definition, and superimposition of structures, the clarity of panoramic radiographs are inferior to intraoral radiographs. Specifically they do not display the fine anatomic detail available in periapical (PA) or bitewing (BW) films. In a study comparing analogue panoramic screening radiographs with PA and full-mouth series (FMS) radiographs in edentulous patients, panoramic
radiographs led to a higher incidence of false positive (FP) and false negative (FN) radiographic findings and failed 25% of the time to show radiographic lesions detected using PA radiographs\textsuperscript{18, 31}. Additionally, there is overlap of anatomical structures and adjacent teeth, especially in the premolar region, as well as superimposition of soft tissues, the spine and ghost images, which all reduce diagnostic quality of the radiograph\textsuperscript{5, 18}. Since pantomography is a modified tomographic technique (imaging by sections) there is tomographic blur or distortion of all structures outside the image layer. Finally, there is unequal magnification and geometric distortion across the image. In panoramic radiography the magnification ranges from 10-30\%, with the horizontal magnification varying considerably depending upon the relationship of the anatomical structure and the focal trough, which are both dependent upon patient positioning\textsuperscript{5, 18}. In short, objects outside the image layer can be blurred, magnified or minimized in size, and are sometimes distorted to the extent of being unrecognizable and of little value diagnostically\textsuperscript{18}.

1.1.2 Positional Errors Within Panoramic Radiographs

Failure to ensure that an edentulous patient is properly positioned so the mandible is correctly placed within the focal trough (image layer) can reduce the value of the panoramic image due to anatomical distortions, potentially leading to a non-diagnostic image\textsuperscript{5, 18, 21, 32}. This can lead to missed radiographic findings or increased radiation exposure to the patient if a retake is required. Thus, it is critical to observe proper patient positioning.

To obtain a clear image with minimal distortion, the mandible (and teeth) should be properly positioned within the focal trough. If, however, an anatomical structure is positioned anterior to the focal trough (closer to the sensor, which moves around the front of the patient), the structure will appear minimized on the panoramic image. Additionally, if an object is in the
anterior region it will appear thinner (decreased width) in the horizontal (mesio-distal) dimension when positioned too far forward. Conversely, if the anatomical structure is positioned posterior to the focal trough (further from the sensor), it will appear magnified on the panoramic image and if its in the anterior region, it will appear wider in the horizontal (mesio-distal) dimension. Thus, as a result of incorrect patient positioning, a lesion could appear enlarged (worsening) or reduced (healing) on successive images or, in extreme cases, disappear completely depending on its anatomical location and placement relative to the focal trough. An additional feature seen in many current digital panoramic machines, such as the ProMax Planmeca used in this study, allows the operator to control the size and shape of the focal trough, which can help to position the mandible correctly.

Several anatomical landmarks and aids can be used to help position the patient correctly and thus minimize distortion by placing the patient within the focal trough: Frankfurt plane (superior tragus to apical portion of orbit), mid-sagittal line (midline), canine line (ala of the nose), and either a bite stick and chin rest for dentulous patients or a chin cup for edentulous patients. Despite these guides, positioning errors continue to occur and have been reported to be much higher in edentulous patients even with trained dental technicians. Possible reasons for the increased difficulty of correctly positioning or detecting errors in an edentulous patient include the following: patient positioning instructions are described for the dentulous individual, soft tissue of the chin misplaces the actual mandible in the focal trough, tooth loss coupled with bone resorption can lead to 2-3cm of dimensional change that can be unaccounted for, increased chronic disabilities seen within edentulous patients can make it more difficult to manipulate the patient position, and finally the presence of teeth allows for the majority of positional errors to be detected by distortion in the teeth, which is not the case in the edentulous patient.
The common positional errors seen on panoramic radiographs reported in the literature include: patient too far forward/posterior, chin too high/too low, head tilted, head turned (rotated), head shifted (midline is off bite-fork), patient movement, tongue not raised to the palate, and patient slumped\textsuperscript{20, 21, 25, 32, 33}. These positional errors can be identified by specific characteristics seen on the panoramic image as described in \textbf{Table 1} and seen in \textbf{Fig 1-5}. They are generally more easily noticed in the dentulous patient because the teeth provide additional clues.
Table 1: Manifestations of common positioning errors on panoramic radiographs

<table>
<thead>
<tr>
<th>Positioning Error</th>
<th>Manifestation detected on panoramic radiograph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tongue not Raised (Palatoglossal Air Apace)</td>
<td>Radiolucent band or dark shadow obscuring maxillary apical areas</td>
</tr>
<tr>
<td>“Chin Down” - Frankfurt plane tipped too low</td>
<td>Excessive curving of occlusal plane; exaggerated “smile;” mandible shaped like a “V;” decreased intercondylar distance; heads of condyles may be projected off the top of the film; spine forms arch or “gazebo” effect and may be superimposed on condyles; hard palate flares upward; roots of the lower anterior teeth become blurry; teeth become severely overlapped; max/mand arches and teeth become disproportionate as maxilla minimizes and mandible magnifies</td>
</tr>
<tr>
<td>“Chin Up” – Frankfurt plane tipped too high</td>
<td>Occlusal plane appears flat or inverted (i.e. “reverse smile”); radiopaque shadow of hard palate is superimposed on roots of maxillary teeth; increased intercondylar distance, heads of condyles may be projected off the edge of the film; orbits appear wider and larger; roots of maxillary teeth become blurry; max/mand arches and teeth become disproportionate as maxilla magnifies and mandible minimizes</td>
</tr>
<tr>
<td>Head Rotated/Twisted/Turned (Midsagittal correct, but patient looking to side)</td>
<td>Bite-stick is in dental midline but unequal right-left magnification particularly in teeth and ramus (i.e. teeth/ramus are wide on one side, narrow on other side of midline); severe overlap of contact points and uneven blurring of teeth; nasal structures not clear e.g. head rotated to right (i.e. looking right) → bite-stick in midline, but right side larger (right ramus is further from sensor)</td>
</tr>
<tr>
<td>Head Shift (Midsagittal incorrect)</td>
<td>Bite-stick is not in dental midline so unequal right-left magnification particularly in teeth and ramus; severe overlap of contact points and uneven blurring of teeth e.g. head shifted to right → bite-stick not in midline, but right side smaller (closer to sensor) and left side larger (further from sensor)</td>
</tr>
<tr>
<td>Slumped Position</td>
<td>Radiopacity in anterior midline that represents superimposition of ghost image of the cervical spine</td>
</tr>
<tr>
<td>Head Tilt</td>
<td>Condyles appear unequal in height; nasal structures distorted; uneven slant in maxilla and mandible to floor (i.e. measure bilaterally from angle of mandible to bottom edge of film)</td>
</tr>
<tr>
<td>Patient too far Back/Posterior</td>
<td>Anterior teeth blurry and wide (i.e. further from sensor); ghosting of rami; condyles close to lateral edge of film or off; ears and nose on image; spread out turbinates</td>
</tr>
<tr>
<td>Patient too far Forward/Anterior</td>
<td>Anterior teeth blurry, small and narrow; spine visible on side of film; superimposition of spine on ramus; bicuspid overlap bilaterally; orbits closer together</td>
</tr>
<tr>
<td>Patient Movement</td>
<td>Portions of radiograph are blurred; large step defects in inferior border of mandible</td>
</tr>
<tr>
<td>Artifacts</td>
<td>Removable prostheses, earrings, necklaces, hearing aids, lead apron create radiopaque images that can cause superimposition and ghost images obscuring anatomical structures</td>
</tr>
</tbody>
</table>

Note: objects closer to sensor (ahead of focal trough) are minimized; further from sensor (behind focal trough) are magnified

5 Out of 21, 25, 33, 34
Figure 1: Edentulous patient with chin down.
Mandible shaped like a “V;” decreased intercondylar distance (because closer to the sensor); spine forms arch or “gazebo” effect and may be superimposed on condyles; hard palate flares upward.

Figure 2: Edentulous patient with chin up.
Occlusal plane appears flat or inverted (i.e. “reverse smile” or a “frown”); radiopaque shadow of hard palate is superimposed on roots of maxillary teeth; increased intercondylar distance, head of the condyles may be projected off the edge of the film; orbits appear wider and larger (the latter three occur because these structures are further from sensor).
Figure 3: Edentulous patient with head rotated to the left.  
*Bite-stick is in midline* but unequal right-left magnification; (i.e. left ramus is wider as it is further from sensor with patient looking left)

Figure 4: Edentulous patient with head shifted to the right.  
*Bite-stick is not in midline* making left ramus appear wider (magnified as it is further from sensor); also see patient is slumped with radiopacity over midline
In addition to using guidelines and anatomical landmarks for proper patient positioning, some simple instructions should also be given to patients to ensure an adequate panoramic radiograph is made without artifacts. Dental appliances or prostheses, earrings, necklaces, hairpins, hearing aids and any other metallic objects in the head and neck region should be removed. The neck should be extended and shoulders dropped by using a gentle upward force on the mastoid eminences. Lastly, patients should be instructed to swallow and hold the tongue to the roof of the mouth and remain still until the panoramic radiograph is completed\textsuperscript{5}.

Patient malpositioning is only one source of errors seen in panoramic images of edentulous patients. The other source of imaging error is technical/processing errors that include: under/over exposure of film, incorrect labeling, solution residue, fingerprints on film, screen damage, static electricity, film crooked in cassette, fog, and chemical streaks\textsuperscript{20, 22, 33}. However, many of these processing errors do not apply to digital panoramic radiographs or can be corrected with the software so are of little consequence to digital imaging and will not be discussed further\textsuperscript{35, 36}.  

Figure 5: Edentulous patient slumped and head tilt slightly to the left
Due to the high level of errors found in panoramic radiographs, the National Radiation Protection Board (NRPB) guidelines from the UK recommend international quality standards or targets of “not less than 70% excellent, not greater than 20% diagnostically acceptable and not greater than 10% unacceptable”\(^{20, 35}\). “Excellent” requires the panoramic image to be error free; “diagnostically acceptable” indicates one or more error(s) existed; and “unacceptable” means the radiograph has “virtually no value, and merely add[s] to patient radiation dose” because it requires a retake\(^{20, 21}\). However, multiple studies that reviewed positional errors on panoramic radiographs concluded that the NRPB guidelines are not realistic or achievable. They suggested the guidelines should remove the category “excellent,” and concentrate on reducing “unacceptable” panoramic images to less than 10% with an aim of 90+% acceptable panoramic images\(^{20, 21}\).

1.1.3 Literature Review on Positional Errors Detected on Panoramic Radiographs

Different studies have shown a range (0 – 37.61%) of panoramic radiographs without errors\(^{32, 35}\) (Table 2). The average percentage of positional errors was 89.2% from the studies identified in Table 2, with a range of errors from about 62-100%\(^{20, 21, 32-35, 37, 38}\).

Table 2: Distribution of errors in panoramic radiographs

<table>
<thead>
<tr>
<th>Report</th>
<th>Distribution Number</th>
<th>Percent with Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schiff et al., 1986(^{39})</td>
<td>1000</td>
<td>79.7</td>
</tr>
<tr>
<td>Brezden et al., 1987(^{38})</td>
<td>500</td>
<td>93.4</td>
</tr>
<tr>
<td>Glass et al., 1994(^{35})</td>
<td>75</td>
<td>92</td>
</tr>
<tr>
<td>Rushton et al., 2002(^{16})</td>
<td>1813</td>
<td>99.2</td>
</tr>
<tr>
<td>Akarslan et al., 2003(^{22})</td>
<td>460</td>
<td>62.4</td>
</tr>
<tr>
<td>Kullman &amp; Joseph, 2006(^{35})</td>
<td>199</td>
<td>100</td>
</tr>
<tr>
<td>Kaviani et al., 2008(^{37})</td>
<td>250</td>
<td>92.4</td>
</tr>
<tr>
<td>Bissoon et al., 2012(^{24})</td>
<td>1000</td>
<td>95</td>
</tr>
<tr>
<td>Dhillon et al., 2012(^{41})</td>
<td>1782</td>
<td>89</td>
</tr>
</tbody>
</table>
Interestingly, Akarslan et al, had the lowest error rate at 62% and their panoramic radiographs were made by trained dental assistants. Due to the abundance of errors identified in panoramic radiographs, many authors feel an “excellent” image quality (free of errors) is not essential or clinically practical for it to be diagnostic.

Studies examining positional errors in panoramic radiographs of edentulous jaws show a failure to position the tongue against the palate\textsuperscript{20,21,32,40}, head rotations to the left/right\textsuperscript{34,37} or chin positioning\textsuperscript{33} as the most common errors detected (Table 3).

The overall high percentage of errors seen on panoramic images of edentulous patients reiterates the importance of correct patient positioning in order to increase the diagnostic benefit of the radiographic image and minimize patient radiation dosage.

**Table 3: Relative distribution of positional errors detected on panoramic radiographs of edentulous jaws**

<table>
<thead>
<tr>
<th>Report</th>
<th>Number and Percent of Total Positional Errors*</th>
<th>Other Error**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shifts</td>
<td>Rotations</td>
</tr>
<tr>
<td>Dhillon et al., 2012\textsuperscript{21}</td>
<td>N/A</td>
<td>310</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bissoon et al., 2012\textsuperscript{34}</td>
<td>N/A</td>
<td>664</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Akarslan et al., 2003\textsuperscript{32}</td>
<td>45</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>5.78%</td>
<td>6.80%</td>
</tr>
<tr>
<td>Rushton et al., 1999\textsuperscript{20}</td>
<td>508</td>
<td>642</td>
</tr>
<tr>
<td></td>
<td>11.26%</td>
<td>14.22%</td>
</tr>
<tr>
<td>Glass et al., 1994\textsuperscript{33}</td>
<td>N/A</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.72%</td>
</tr>
<tr>
<td>Avg. of Studies</td>
<td>3.4%</td>
<td>13.0%</td>
</tr>
</tbody>
</table>

* % is percent of total errors (so totals 100%) and not percentage of panoramic radiographs
** Other = tilt, artifact, anterior-posterior, movement, slumped, superimposition of hyoid;
1.2 Digital Radiographs

Digital imaging systems designed exclusively for dentistry have been available for three decades since Dr. Frances Mouyens invented the RadioVisoGraphy (RVG) in 1984 to replace film-based radiography. Since then the advent of digital imaging has revolutionized radiology due to the innovations in image acquisitioning and “processing” techniques, as well as the ability to store, transmit, manipulate and enhance the information electronically. The term digital in the most literal sense means to turn information into a numeric format by breaking it down into discrete bits of information or digits (i.e. binary code of 0s and 1s). Digital radiographs are numeric and discrete in two ways: i) in terms of spatial distribution of the pixels (discrete “picture elements” that form the digital image), which are uniquely positioned within rows and columns to precisely identify their location within the sensor matrix; and ii) in terms of different shades of gray for each of the pixels as a result of x-ray absorption at that particular location within the sensor. The formation of the digital image is the result of x-ray photon interactions with electrons within the sensor pixels. It requires a process called analog-to-digital conversion (ADC), which consist of various steps. The two main steps are sampling and quantization. The ADC transforms analog data in the form of voltages generated by absorbed x-rays at each pixel on the sensor into the digital numerical or binary system. This is accomplished by grouping a small range of voltage values together as a single value in the process known as sampling. A narrow sampling better mimics the original signal but leads to large memory requirements. Then each sampled signal is assigned a value from zero (black) to 255 (white) in the quantization step. These numerical assignments translate into 256 shades of gray/different densities. In essence, the conversion of the voltage at each
pixel is amplified and converted to a gray value based on the intensity of the x-ray photons hitting the receptor.

Some digital systems sample the raw data at a contrast resolution of more than 8-bits per pixel, equivalent to 256 shades of gray/different densities, which is the maximum that a conventional computer monitor can display. However, the higher contrast resolution systems can reach 12-bit (4,096 shades of gray) and 16-bit (65,536 shades of gray), which can only begin to be seen on a medical gray scale diagnostic grade (MGDG) monitor and are of no additional benefit on a conventional monitor using a Windows™ operating system.5,23,41,45 Despite this great contrast resolution, the human eye can distinguish on average about 32 shades of gray, and up to 60 under ideal lighting conditions5,41,45.

Once the data have been transformed from the analog or voltage form into the numeric or digital form it is then directly or indirectly transferred to the computer depending on the radiographic sensor type – this will be discussed later. Once the image is displayed on the computer screen it is ready for interpretation, where it can be manipulated, unlike traditional analog films, via image processing techniques to aid in diagnosis.5,41,43 Once the digital receptor is exposed to the x-ray photons after they pass through the different tissue layers to form a latent image voltage readout, the image is either directly converted to an electronic image that is transferred straight to a monitor or it is “processed” (scanned) indirectly to a monitor where it can viewed by the clinician. The technology in the digital receptors is what allows a decrease in exposure time to the patient, as digital sensors do not change the way the x-rays are selectively attenuated by the different tissue densities they pass through prior to hitting the receptor5.
1.2.1 Digital Terms

Prior to discussing digital sensors and the advantages digital radiography has to offer, the terms associated with digital radiographs and technology will be reviewed (Table 4).

Table 4: Terms used in digital radiology

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>DICOM – Digital Imaging and Communication in Medicine</td>
<td>Usual electronic data image storage format; the international standard language for electronic communication of digital images</td>
</tr>
<tr>
<td>Brightness (Luminance)</td>
<td>Digital equivalent to density or overall degree of image darkening</td>
</tr>
<tr>
<td>Contrast Resolution</td>
<td>Ability to distinguish differences in density in radiographic image as displayed on a monitor; measured in bits (i.e. 8 bit = 256 shades of gray or different densities)</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>Numerical range of each pixel (picture element); in visual terms, it refers to the number of shades of grays that can be represented</td>
</tr>
<tr>
<td>Spatial Resolution/Frequency</td>
<td>Capacity to distinguish fine detail in an image or between 2 small objects that are close together; measured in line pairs per millimeter (lp/mm); limited by pixel size (the smaller the size of the pixel, the higher the resolution); observers generally can distinguish about 6-10 lp/mm without magnification</td>
</tr>
<tr>
<td>Detector Latitude</td>
<td>Ability of an image receptor to capture a range of x-ray exposures (or tissue densities); the greater the latitude the greater the ability to see a large range of tissue densities and even subtle differences within one kind of tissue</td>
</tr>
<tr>
<td>Detector Sensitivity</td>
<td>Equivalent to analog film speed, the sensor’s ability to respond to small amounts of radiation</td>
</tr>
<tr>
<td>Background Electronic Noise</td>
<td>Small electrical current that conveys no information but can obscure the electronic signal, similar to radiographic mottle (graininess) in analog film</td>
</tr>
<tr>
<td>Signal to Noise Ratio</td>
<td>Ratio between the diagnostic output (signal) measured by voltage/charge, and the non-diagnostic output/information (noise); it has been compared to sharpness or ability to define an edge or display density boundaries in analog film</td>
</tr>
</tbody>
</table>
1.2.2 Digital Receptors/Sensors

There are two main types of receptors or sensors used in digital radiography: solid-state electronic sensors (also known as corded-sensors, which capture and digitize the image directly) and PSP plates/receptors (also known as non-corded or “wireless” sensors, which capture the image indirectly)\(^5,23,41-45\). A better name for the solid-state sensor is the direct sensor, whether there is a cord or not because now some of the silicon chips connect to the computer via a radio signal rather than a cord\(^44\). Similarly, a more appropriate name for the PSP plate is the indirect sensor, because once the image is captured on the phosphor-coated plate a scanner is required to “process” or acquire the digital image prior to viewing\(^44\). Examples of solid-state electronic sensors or direct-imaging based sensors are the charged-coupled devices (CCD), complementary metal oxide semiconductor (CMOS) and flat panel detectors\(^5,23,42,44,45\). Flat panel detectors are being used for medical imaging mainly, leaving CCD and CMOS chips currently in use for dentistry. Functionally, there are many differences between the CCD and CMOS, but clinically speaking there does not appear to be a significant advantage to one form of solid-state sensor over the other\(^5,44\).

The first digital radiography on the market was the CCD, which was introduced to clinical practice in the late 1980s\(^5,23,42\). The CCD uses a reusable image receptor composed of an array of pixels on a silicon chip that are sensitive to X-rays and visible light, essentially forming photoelectric cells (or electron wells). The array of pixels is either in an area-array for intra-oral receptors or a linear-array of pixels for extra-oral receptors. The pixels within the receptor are composed of silicon atoms covalently bonded to each other. Once exposed to X-rays or light photons, the covalent bonds break apart and the photoelectric cells (pixels/electron wells)
generate voltage in proportion to the amount of radiation energy\textsuperscript{23, 41, 42}. The receptor is connected directly to a computer via a cable producing an image in less than 5 seconds providing real-time imaging following the ADC\textsuperscript{42, 44}. The nearly instantaneous image is desirable for oral surgery, endodontics and implant placement\textsuperscript{5}.

CCD receptors are available in size 0, 1 and 2 comparable to PA and BW intraoral films. In general, CCD receptors have higher detector sensitivity than both analog film or PSP and thus require less radiation exposure\textsuperscript{5}. However, the sensors are bulky and rigid making them more uncomfortable than film or PSP plates and can make the correct placement of the sensor difficult\textsuperscript{23, 41}. The active area capable of creating a digital image is smaller than the sensor size, which can sometimes lead to a loss of information\textsuperscript{41, 45}. CCD receptors are also made for panoramic and cephalometric imaging\textsuperscript{41, 45}. The digital panoramic machine used at UBC is the ProMax Planmeca (Helsinki, Finland), which uses a CCD sensor.

The first photostimulable phosphor plates, DigoRa, became commercially available in 1994\textsuperscript{42}. The PSP consists of a polyester base coated with a europium doped crystalline halide (barium fluorohalide) emulsion that converts X-ray into stored energy. The europium creates imperfections within the emulsion lattice that when exposed to sufficient energy in the form of radiation can release europium electrons, which become trapped in a metastable state in nearby halogen vacancies. The number of trapped electrons is proportional to the X-ray exposure and represents a latent image\textsuperscript{5}. In essence, the phosphor crystalline layer is able to store the energy of the X-ray photons until it scanned\textsuperscript{23}. Once the PSP is scanned via a red light (600nm) or a helium-neon laser the energy stored in these crystals is released as a blue-phosphorescence. This emitted green-blue light (between 300-500nm) is a measure of the X-ray energy absorbed and is captured and conducted by fibreoptics from the PSP to a photomultiplier tube, which intensifies
and converts the light into a voltage that is quantified by the ADC and finally displayed into a
digital image. Not all the energy stored in the PSP is released during the scanning process.
Therefore, each of these plates must be erased to remove any residual energy or ghost images by
flooding with a bright light for 1-2 minutes and then disinfected and sealed in polyvinyl
envelopes prior to re-use\textsuperscript{5, 23, 41, 44, 45}. Although the PSP plates can be erased, they do have a
limited lifespan of many years, allowing them to be re-used hundreds of times before being
replaced at an average cost of $40/sensor\textsuperscript{46}.

Using an indirect PSP plate can take up to as many as 10 steps from initiating the
radiograph prior to re-use of the intra-oral PSP sensor. As well, the image can take minutes to
become available for viewing, similar to analog film-based radiography\textsuperscript{23, 44}. When
manufactured, PSP plates are similar to film, i.e. they are flexible and come in the same intraoral
and extraoral sizes (PA, BW, occlusal, panoramic and cephalometric) making them familiar and
similarly comfortable to the patient. One big advantage of the PSP sensor is that it can be used
in the same cassette holders as an analog film for panoramic radiography. Also, the entire sensor
is able to capture a latent image, unlike its CCD counterpart\textsuperscript{5}. Additionally, current PSP
technology for intraoral radiography allows for dose reductions of about 50\% in comparison to
F-speed film with similar diagnostic performance with a greater detector latitude than either film
or solid state detectors\textsuperscript{5}. However, due to this broad detector latitude, PSP images can be
overexposed more than is necessary for diagnostic quality and still provide good image quality,
potentially exposing patient to increased radiation if the operator is not careful\textsuperscript{23, 41, 43}.

A 2013 study comparing the diagnostic image quality (anatomical coverage, density and
image contrast) of digital panoramic radiography (with and without post-processing or image
enhancement) versus a conventional analog panoramic radiograph\textsuperscript{47} found that both digital
panoramic radiographs scored higher by two blinded evaluators compared to conventional radiographs. It was concluded that digital panoramic radiography with post-processing (which scored the highest of the three groups) can improve diagnostic quality significantly in terms of radiographic density and contrast\textsuperscript{47}.\footnote{\textsuperscript{47}}
Table 5: Comparison of charge coupled device (CCD), photostimulable phosphor plates (PSP) and Film\textsuperscript{5,41,48,49} (Adapted from MacDonald DS. Factors to consider in the transition to digital radiological imaging. Journal of the Irish Dental Association. 2009; 55:26-34).

<table>
<thead>
<tr>
<th>Feature</th>
<th>CCD</th>
<th>PSP</th>
<th>Film</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image Formation</td>
<td>X-rays cause emitted electrons to collect in electron wells/pixels which are converted to grayscale image instantly via ADC process (COMPUTER)</td>
<td>Phosphor coating absorbs X-ray energy and is scanned under red light, emitting blue light energy converted to grayscale image via ADC process (SCANNER &amp; COMPUTER)</td>
<td>X-ray causes silver bromide to release electron filled by metallic silver (density of which provides grayscale) once developed in chemicals to provide grayscale latent image (CHEMICAL)</td>
</tr>
<tr>
<td>Image Viewing Time</td>
<td>Instant – real time on computer monitor</td>
<td>Delayed – scanned to computer monitor</td>
<td>Delayed – processed for transillumination on viewbox</td>
</tr>
<tr>
<td>Receptor Construction</td>
<td>Thick, rigid (usually have cord)</td>
<td>Thin, flexible</td>
<td>Thin, flexible</td>
</tr>
<tr>
<td>Receptor Sizes</td>
<td>PA, BW, Panoramic &amp; Lateral Cephalometric; No Occlusal</td>
<td>PA, BW, Occlusal, Panoramic &amp; Lateral Cephalometric</td>
<td>PA, BW, Occlusal, Panoramic &amp; Lateral Cephalometric</td>
</tr>
<tr>
<td>Exposure Time</td>
<td>Similar to E and F speed film (i.e. similar detector latitude to film)</td>
<td>Potential to be shorter than film (because increased detector latitude)</td>
<td>Good if E and F speed film</td>
</tr>
<tr>
<td>Detector Sensitivity (speed)</td>
<td>Highest</td>
<td>Slightly higher than film</td>
<td>Lowest</td>
</tr>
<tr>
<td>Radiation Dose</td>
<td>Lower*</td>
<td>Lower*</td>
<td>Higher</td>
</tr>
<tr>
<td>Detector Latitude / Dynamic Range (ability to distinguish a range of densities)</td>
<td>Narrow: similar to film, but can be enhanced by changing contrast and brightness</td>
<td>Wide or greatest: 5 orders of magnitude</td>
<td>Narrow or Least: the useful range is 2 orders of magnitude and no enhancement capability</td>
</tr>
<tr>
<td>Spatial Resolution (ability to distinguish 2 objects close together)</td>
<td>16 lp/mm</td>
<td>20 lp/mm (theoretically up to 25 lp/mm)</td>
<td>20+ lp/mm</td>
</tr>
<tr>
<td>Retakes More Likely</td>
<td>Yes – cone cut (because placement can be difficult and receptor surface not entirely for image capture)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Special Room Required</td>
<td>No</td>
<td>Yes – dim room with scanner</td>
<td>Yes – dark room with chemical developers and another for viewbox</td>
</tr>
<tr>
<td>Lifespan of Receptor</td>
<td>Reusable – 10,000 exposures?</td>
<td>Reusable after erasure</td>
<td>Single use</td>
</tr>
<tr>
<td>Infection Control</td>
<td>Yes – barriers needed, cannot autoclave</td>
<td>Yes – decontaminated with alcohol wipes then recovered with barrier</td>
<td>No – disposable after single use</td>
</tr>
<tr>
<td>Image Enhancement</td>
<td>Yes</td>
<td>Yes</td>
<td>No – fixed, unchangeable image after developed</td>
</tr>
<tr>
<td>Storage</td>
<td>Archived on server, Zip or CD</td>
<td>Archived on server, Zip or CD</td>
<td>Patient’s paper chart</td>
</tr>
</tbody>
</table>

* Dose reduction is dependent on several factors, such as film speed, collimation shape, exposure time and number of retakes (due to position errors, technical errors)
1.2.3 Advantages of Digital Radiographs

An alternative to digital radiography is conventional film radiography, otherwise known as analog. Film radiography has generally fallen out of favour due to higher radiation exposure of the patient, chemical processing errors, the need for continual monitoring and replacement of hazardous chemicals to process the latent image, the purchase and storage of radiographic holders and the lack of post-image processing\textsuperscript{2, 5}.

One of the main advantages of digital radiographs is the post-image processing\textsuperscript{8, 23}. Unlike film-based radiography, both CCD and PSP digital modalities allow the user to perform post-processing modifications to the radiographic image so factors such as brightness or contrast do not have to remain fixed. Image processing allows digital images to be manipulated because the computer software allows the user to apply mathematical operations to alter the pixel values, therefore changing certain characteristics of the image\textsuperscript{43}. One can optimize the brightness to correct for overexposure and underexposure of an image (possibly preventing the need for a retake). The contrast resolution can be adjusted to improve density characteristics to aid in diagnosis. For example, one could increase the contrast to enhance the differential diagnosis of dental cavitation, or decrease the contrast to assess periodontal bone lesions\textsuperscript{43}. In a 1996 review paper\textsuperscript{18} it was reported that along with positional errors, the most frequent causes of inadequate panoramic radiographs included low density and low contrast films\textsuperscript{18}, which can be improved with digital radiography. This was also supported in a 2013 study\textsuperscript{47} comparing the diagnostic image quality (anatomical coverage, density and image contrast) of digital panoramic radiography with and without post-processing versus conventional panoramic radiographs, which found that image enhancement can improve the density and contrast of a digital image\textsuperscript{47}.
Additionally, part of post-processing image enhancement is the ability to change linear contrast, invert the gray scale (black-white reversal) to evaluate the “negative image,” magnify, enhance edges, and measure distances\(^2,5,43\). In short, a digital image can be adjusted for optimal diagnostic quality, including alterations in contrast, density, magnification and colour making an average image excellent\(^2,44\).

The ability to enhance the image post-processing does not negate the need to produce the radiographic image with a correct exposure time and patient positioning, but it can minimize radiation exposure to both the health care provider and the patient, highlighting the other main advantage of digital radiographs, namely radiation dose reduction\(^2, 23, 42, 50\). The use of digital radiographs decreases the technical (or processing) faults that can occur with analog or film radiography, leaving positional errors to attend to\(^21\), which can reduce the need for retakes and thus patient radiation dose. As well, given the detector sensitivity of CCDs and PSPs compared to analog film, they both require less exposure to radiation to obtain the same diagnostic quality\(^5, 45\).

Dose reduction has been reported to be as high as 90% in some studies and according to manufactures’ claims\(^24, 42, 43\). In one study, the average dose reduction using digital radiography was reported to be 70% for intraoral images and 42% for panoramic radiographs\(^51\). However, others argue that the reality may be a 0-50% reduction in dosage compared to the current standard F-speed film\(^18, 43\). In a study conducted with phantom heads, a reduction of the radiation dose by 47% for 14-intraoral radiographs and 17% for the panoramic radiograph was reported when switching from analog to digital radiographs\(^51\).

The amount of dose reduction ultimately depends on the equipment used and the settings applied, the speed of the analog film being compared, and the care the practitioner uses to ensure
that proper barriers and exposure times have been followed\textsuperscript{43}. The overall reduction in radiation exposure of digital radiographs might not be as low as expected due to an increase in number of radiographs taken, a decreased interval before new radiographs are taken and the ease of remaking an erroneous image, all of which may stem from the overall knowledge that digital radiographs reduce the ionization dosage per exposure\textsuperscript{2, 42, 43, 51}. However, many clinicians who use PSP and CCDs tend to take more radiographs than they did when using analog films\textsuperscript{43}. Other advantages of digital radiography include instant images, convenient storage and transmission of radiographic images, elimination of hazardous processing chemicals and reduced long-term operational costs\textsuperscript{2, 5, 41, 45, 47}.

1.3 Radiation Basics

Radiation is the transmission of energy through space and matter in the form of sub-atomic particles [alpha (α) and beta (β) particles] and electromagnetic waves. Alpha (α) and Beta (β) particles are a form of radiation created when unstable, large atoms break apart. Unstable atoms are said to be radioactive. In order to reach stability, these atoms emit the excess energy or mass in the form of radioactive particles. Alpha particles quickly ionize the matter through which they pass and thus they penetrate only a few micrometers of tissue. Conversely, β-particles are not densely ionizing and are therefore able to penetrate further into tissue than α-particles up to a maximum of 1.5cm before acquiring electrons and becoming neutral.

Quantum theory considers electromagnetic radiation to be tiny bundles or packets of pure energy called photons that travel through space on a combination of electric and magnetic fields in a wave-like motion. Each photon travels at the speed of light and contains a specific amount of energy. There are many examples of electromagnetic radiation (Figure 6): Gamma (γ) rays,
x-rays, ultraviolet rays, visible light, infrared radiation (heat), microwaves and radiowaves$^5, 12$. According to where in the spectrum electromagnetic radiation falls, it may be ionizing or nonionizing depending on the energy. The process of ionization itself requires a sufficient form of energy to overcome the electrostatic force binding electrons to the nucleus of a neutral atom to strip it of an electron, forming a free radical or free negative ion$^5$.

The energy for electromagnetic radiation is determined by the formula:

$$E = h \times \frac{c}{\lambda}$$

where, $E$ is energy in kiloelectron volts (keV), $h$ is Planck’s constant, $c$ is the velocity of light, and $\lambda$ is the wavelength in nanometers$^5$. Based on the formula, the shorter the wavelength of radiation, the greater the frequency and the larger the energy. X-rays have a high energy and are known to be ionizing. Thus, there are government institutions such as the ICRP and NRPB in place to provide guidelines with respect to x-rays and other forms of ionizing radiation$^2, 12, 52, 53$.

1.3.1 Effective Dose

Radiation is ubiquitous coming from many sources both natural and artificial including cosmic radiation, radon from the ground or earth's crust, radioactive rocks, the soil and the food we ingest\(^5,6,54\). The average annual effective dose related strictly to background radiation is about 2400 microsieverts (µSv) [2.4 millisieverts (mSv)] worldwide and 3100 µSv in the United States of America (USA)\(^4,6,12,55\). This equates to about 8.5 microsieverts (µSv) daily\(^6\). When man-made sources of radiation are included in the calculation, the current estimate of the effective dose per individual rises to 6200 µSv annually in the USA, with about half coming from diagnostic imaging\(^6,54\). The main sources of artificial radiation come from medical diagnostic imaging, with the majority (24%) from CT and 5% from conventional radiography/fluorography for both medicine and dental, of which only half or 2.5% is estimated to be from dentistry\(^54\).

To compare dosages of ionizing radiation among the myriad of sources, the ICRP determined that the effective dose was the preferred unit of measurement to assess the risk for detrimental effects measured in joules per kilogram (J kg\(^{-1}\)) and it was given the special name, sievert (Sv)\(^12,24,52,56,57\). Effective dose is defined as the sum of the equivalent doses (H\(_T\)) in the principal tissues and organs (T), each weighted by a tissue-weighting factor (ω\(_T\))\(^6,52,55,57\). The effective dose is a calculated quantity and cannot be measured\(^55\). The equivalent dose (H\(_T\)) is essentially the mean absorbed dose from radiation in a tissue/organ multiplied by the radiation weighting factor (for x-rays, this value is 1) and the irradiation fraction of the tissue in relation to its total volume in the body (the normal values are described in the literature)\(^6,57\). The tissue-weighting factor (ω\(_T\)) is a dimensionless unit by which an equivalent dose in a tissue or organ (T) is weighted to represent the relative contribution of that tissue/organ to the overall detriment.
resulting from uniform irradiation of the body\textsuperscript{57}. In short, the effective dose was recommended because it considers not only the dose absorbed, but also the type, quantity, radiosensitivity (via the $\omega_T$), and carcinogenic potential of the irradiated tissue, where as the equivalent dose does not consider the type or amount of tissue exposed\textsuperscript{3, 6, 24}. An effective dose will carry the same overall detriment to the individual regardless of where it was applied, and it will carry the same effective risk as the same amount of equivalent dose theoretically and uniformly applied to the whole body\textsuperscript{3}.

As of 2007, the ICRP revised the previously published tissue weighting factors ($\omega_T$) by increasing/decreasing the relative sensitivity of various body tissues to ionizing radiation based on the risks of cancer induction and heritable disease\textsuperscript{6, 52, 56}. For example, the sensitivity of the gonads was decreased from 0.20 to 0.08, breast tissue increased from 0.05 to 0.12, while the salivary glands and the brain were included officially for the first time as important radiosensitive tissues\textsuperscript{52, 56}.

Salivary glands and oral mucosa consistently receive the highest equivalent doses of all tissues from common dental radiographic examinations, thus profoundly impacting the effective doses of dental radiography\textsuperscript{52}. With the inclusion of salivary glands, the effective doses for examinations computed with various speeds of analog film and digital radiographs increased between 32\% to 422\% above previous calculations based on the 1990 ICRP tissue weighting factors\textsuperscript{52}. Both the digital panoramic machines utilizing CCD sensors, the Panoramic Orthophos XG and the Panoramic ProMax, had an increase in effective dose of 231\% and 241\% due to the inclusion of salivary glands when the new ICRP guidelines are applied\textsuperscript{52}. Salivary glands are particularly important in panoramic radiography because the location of the posterior rotational center coincides with the parotid gland and submandibular glands, and the anterior rotational
center coincides with the sublingual glands. Although the areas scanned are only briefly exposed to radiation, anatomical structures at the rotational centers like the salivary glands are exposed continuously\textsuperscript{52}.

1.3.2 Biological Effects of Ionizing Radiation

The standard measurement of effective dose allows one to easily compare different imaging modalities and to calculate the radiation detriment, which is the total harm to an exposed individual and their descendants\textsuperscript{3, 52, 55, 57}. Detriment’s main principles include the weighted probabilities of fatal and nonfatal cancer, relative length of life lost and hereditary effects\textsuperscript{52, 57}. Generally speaking, the detrimental or harmful effects of ionizing radiation are categorized as “tissue reactions”, previously known as deterministic effects, and stochastic effects. As indicated by the $\omega_T$ factor, ionizing radiation has greater effect on cells that are radiosensitive, for example, rapidly dividing cells, cells with many future mitotic divisions, and undifferentiated cells\textsuperscript{5, 54, 56}. In dentistry, this mainly affects salivary glands, the thyroid gland, the brain and bone marrow (leukemia) depending on the imaging technique utilized\textsuperscript{54}. Specifically, dental radiographic imaging has been linked to meningiomas, salivary gland tumours and thyroid tumours\textsuperscript{54}.

Tissue reactions are proportional to the dose and occur in all individuals when the radiation dose is large enough. As the dose increases, the biological or tissue severity also increases, resulting in cell death or malfunction. Depending on the tissue exposed, this can lead to cataracts, skin erythema and mucositis\textsuperscript{7}. However, for the effects to manifest there is a threshold dose, below which no clinical changes are seen. Conventional dental imaging does not cause deterministic effects/tissue reactions because the doses are too low\textsuperscript{7, 54}. The ICRP notes
that, “in the absorbed dose range up to around 100 milligray (mGy) no tissues are judged to express clinically relevant functional impairment”, whether in a single dose or protracted form such as repeated annual exposures\(^5\).

In contrast, stochastic effects do not have a dose-threshold\(^7,54\). However, because they can result in DNA damage leading to cancer or leukemia, and to a much lesser extent heritable/genetic damage, they have become the main focus\(^7,54,56\). It is believed the risk of cancer is cumulative over a lifetime of low-dose exposures and because there is no evidence for a threshold dose, stochastic effects are considered non-reversible, “chance effects” that manifest years after repeated exposures\(^7,14\). The idea that the magnitude of risk for developing a cancer is proportional to radiation dose is based on epidemiological and experimental studies, albeit with uncertainties at doses below 100mSv\(^7\). Additionally, the risk of stochastic effects is age-dependent, being highest for the young and least for elderly people\(^7,14\). The risk for small children is three times greater than that for an adult over 30 years of age\(^7,12\). The risk factor is calculated to be about 5% per Sv according to the ICRP, which theoretically implies that at a dose of 1mSv, the risk for fatal cancer is 0.00005%, or 50 in 1 million people at risk\(^7,56\). All estimates of risk are extrapolated from literature involving human epidemiological studies and survivors of atomic/nuclear exposures and has led to the development of the linear non-threshold (LNT) hypothesis (\textbf{Figure 7})\(^54\). The LNT hypothesis is a dose response model, which is based on the assumption that the risk of excess cancer/heritable disease is linearly related to even the smallest exposure of low-dose radiation above background levels\(^54,57\).
Figure 7: The linear non-threshold (LNT) hypothesis\textsuperscript{54}.
The solid dots on the upper right side of the graph indicate that at higher doses, above those used in diagnostic imaging, there is a known linear relationship between excess cancer rates and dose (Copyright 2012 Wiley. Used with permission from White & Mallya, Update on the biological effects of ionizing radiation, relative dose factors and radiation hygiene, Australian Dental Journal, Australian Dental Association).

Therefore, given the scientific plausibility from epidemiological studies and the LNT model, the ICRP assumes that the incidence of cancer (stochastic effects) or hereditary (genetic) disorders will rise in direct proportion to an increase in the equivalent dose in the relevant organs and tissues, below about 100 mSv\textsuperscript{56}. However, there are relatively few studies showing a risk at the low doses in the diagnostic range of dental imaging. In this low dose range (<100mSv) the LNT is unknown\textsuperscript{54}. The gonads are usually well protected during dental radiography and detrimental hereditary effects are much less likely to occur compared to other stochastic effects, such as cancer\textsuperscript{12,14}. Nonetheless, there is some risk and patients need to be informed about the risks versus benefits of the imaging.

Lastly, there is growing evidence that there are other radiation-associated health consequences – heart disease, stroke, digestive disorders and respiratory disease. However, the ICRP concluded that the data are insufficient to allow for their inclusion in the estimation of detriment following low doses (i.e. <100 mSv)\textsuperscript{56}.
1.3.3 Dosage of Panoramic Radiographs and Relative Risks of Biological Effects

The detrimental biological effects of ionizing radiation should be placed in context with respect to everyday background radiation for the patient and the practitioner. In order to do so it is crucial to have an idea of the effective dose emitted by panoramic machines. This will depend on the model and make, as well as the exposure settings, such as kilovolts (kV), milliamps (mA) and time of exposure (seconds). Additionally, depending on the ICRP version used (1990, 2005 or 2007) different effective doses for panoramic radiographs can be found for the same level of irradiation based on changes to tissue/organ weighting factors. However, recent research that included salivary glands found that dose calculations for digital panoramic machines ranged between 3.85 – 30 µSv, 4.7 – 14.9 µSv, 8.9 – 37.8 µSv and 2.7 – 24.3 µSv. One recent study found a variation in digital panoramic machines between PSP and CCD, with PSP having slightly lower effective dose values of 8.9 µSv and 15.9 µSv compared to 27.6 µSv and 37.8 µSv for CCDs. Average effective dose values of 6.7 µSv and 4.1 µSv have been reported for analog and digital panoramic radiographs, respectively. Specifically, for the digital ProMax Planmeca panoramic machine used at UBC with the average adult settings of 68kV, 13mA and 16 seconds, the effective dose was 7.1 µSv and 24.3 µSv based on the 1990 and 2007 ICRP, respectively. Comparatively speaking, a lateral cephalogram with PSP is 5.6 µSv, a full mouth series (FMS) of digital radiographs or F-speed film with rectangular collimation has an effective dose of 34.9 µSv, and a cone beam CT with a large field of view ranges between 68-182.1 µSv based on the ICRP 2007 guidelines (Table 6).
Table 6: Comparison of effective doses of radiation from different sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Effective Dose (µSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Background Radiation(^5, 6, 54)</td>
<td>8.5</td>
</tr>
<tr>
<td>Analog Panoramic Radiograph(^18)</td>
<td>6.7</td>
</tr>
<tr>
<td>Digital Panoramic Radiograph(^50)</td>
<td>4.1</td>
</tr>
<tr>
<td>Digital Lateral Cephalometric Radiograph(^52)</td>
<td>5.6</td>
</tr>
<tr>
<td>Full Mouth Series (digital radiographs or F-speed film)(^6)</td>
<td>34.9</td>
</tr>
<tr>
<td>Cone Beam Computed Tomography(^6)</td>
<td>68-182.1</td>
</tr>
</tbody>
</table>

Given that the average daily background radiation exposure for an individual is 8.5 µSv, a digital panoramic machine equates to about 8 hours (2.7 µSv/8.5 µSv) to 4.4 days (37.8 µSv /8.5 µSv) of extra background radiation exposure\(^3, 6, 26\). Overall, the effective dose of a panoramic radiograph according to the LNT hypothesis corresponds to a lifetime estimated risk of developing a fatal malignancy of 0.17 – 1.9 per million panoramic exposures compared to 2.5 per million for a FMS\(^3, 5, 12, 14, 18\). Comparatively, the annual fatality rate for smoking is 1:200, heart disease is 1:300, an accident in the home is 1:15,000, an accident on the road is 1:17,000 and per 1000 µSv is 1:20,000\(^7, 57\).

In summary, the biological effects of ionizing radiation emitted by panoramic radiographs remains uncertain, but probably have less risk than many of us take in our daily lives\(^58\). Nevertheless, dentists should not assume the risk of diagnostic imaging is zero and should inform the patient of the risks, benefits and justification for the diagnostic imaging\(^14, 58\).

1.4 Arguments For and Against Screening Panoramic Radiographs

Despite North American and European guidelines for prescribing dental radiographs, there are still opposing viewpoints on using panoramic radiographs to screen for abnormalities in the jaws of edentulous patients. A ‘routine’ or ‘screening’ radiographic examination is defined
as one conducted regardless the presence or absence of clinical signs and symptoms\textsuperscript{32}. The discordant viewpoints probably are due to the clinical discretion permitted by guidelines that were developed to help clinicians exercise their clinical judgment\textsuperscript{1, 2, 9, 11, 12}.

1.4.1 Arguments Against Screening Panoramic Radiographs

The first and most obvious reason against screening panoramic radiographs is that the guidelines in North America (NA) and the United Kingdom (UK) are evidence-based\textsuperscript{1, 2, 8, 12}. That evidence indicates that a radiograph should be prescribed after a thorough clinical exam and a review of the patient’s history and S&S, forming a fundamental requirement of radiation protection\textsuperscript{2, 3, 7-9, 11, 12, 27, 57, 59, 60}. The results obtained from the process of performing a comprehensive clinic examination and review of the patient’s history and S&S is the justification for an individualized radiographic prescription, a cornerstone to the ALARA principle. It helps to avoid the deliberate use of screening radiographs for edentulous patients, or any patient. The ADA specifically states that the need for a careful clinical exam applies to new edentulous patients not just dentulous patients to provide justification for a radiograph\textsuperscript{2}. In Europe, seeking clinical justification to prescribe a radiograph is not just a guideline, but a legal requirement according to the Radiographic Referral Criteria and should be seen as an ethical obligation as well\textsuperscript{3-9}. This legal requirement falls under “duty of care,” which states that one must reasonably foresee that their conduct may cause harm\textsuperscript{61}. Thus, when there is no clinical justification based on past dental and medical histories and S&S, by not prescribing a screening radiograph no probable harm will foreseeably come to the patient. Nonetheless, 42\% of dental practitioners in the UK and 53\% in NA practice routine use of panoramic radiology on new adult patients
without any clinical findings to support the prescription in order to “screen” the jaws for clinically unsuspecting pathoses\textsuperscript{3, 28, 62}.

Additionally, the guidelines in the UK clearly state that medico-legal fears associated with missing asymptomatic, occult pathoses should not influence radiographic prescription\textsuperscript{27}. If a complaint arises against a dentist with regards to radiation exposure, the dentist should be able to demonstrate they followed a defensible course of action, mainly selection criteria, as a basis for justification of any radiograph\textsuperscript{11}. Additionally, it should be noted that disclosure of information about remote risks, such as missing an asymptomatic PRF that has a high degree of morbidity, is plausibly argued against and easily defended on the clinician’s behalf, as being mainly a “symbolic” injury to the patient’s dignity and integrity and not an incidence of professional neglect or poor informed consent\textsuperscript{63}. Selection criteria can be defined as “descriptions of clinical conditions observed from patient signs, symptoms and history that identify those patients who are likely to benefit from a particular radiographic examination”\textsuperscript{3, 18}.

Based on previous research examining radiographic selection criteria, the conclusions explicitly state there is no justification for screening panoramic radiography at arbitrary intervals and that routine screening radiographs should not be a regular practice\textsuperscript{2, 9, 11, 59, 60}.

The use of selection criteria can reduce the number of total radiographs taken by 43\% and the number of panoramic radiographs by 73\% without missing undiagnosed disease\textsuperscript{2, 8, 64}. The use of selection criteria also increases the likelihood that the patient will receive a “net benefit” (to be discussed later) from the radiographic examination\textsuperscript{19}. Two studies from the 1980s\textsuperscript{64, 65} found that by utilizing selection criteria in edentulous patients along with the appropriate use of intra-oral radiographs, a clinician could significantly reduce the number of panoramic radiographs taken with only a 6-7\% risk of missing a radiographic finding that might influence
In Kogan and Stephan’s study, only 1 out of 54 patients benefited from a panoramic radiograph after using selection criteria protocols. The evidence surrounding panoramic radiographs indicates that “the value of the panoramic radiograph [is] best in patients for whom it was obtained for a specific purpose” as achieved through selection criteria and is “poorest when it [is] prescribed for nonspecific screening purposes.”

By following selection criteria to ensure that each radiograph prescribed is clinically justified, the patient is more likely to receive some value or a “net benefit” from the panoramic imaging. In the simplest terms, a “net benefit” arises when the diagnostic value of the radiographic examination outweighs or proves more favorable compared to the individual detriment the radiation dose might cause. A net benefit implies that a PRF affects the management or prognosis of the patient. Thus, others have challenged that simply having a high yield of PRFs seen in a screening panoramic radiograph does not equate to a clinically relevant finding or a net benefit to the patient. In order for a PRF to represent a net benefit to the patient, others have suggested it should represent a “true” pathosis or pathological condition such as osteitis, metabolic conditions, malignancy, or a destructive tumour/cyst, pose a health risk, affect denture fabrication, require further radiological review or a referral, or as stated previously, affect the management or prognosis for a patient. Subscribing to this concept of net benefit, the value of a screening panoramic radiograph is determined by the proportion of PRFs that impact treatment planning and not simply on the high percentage of occult PRFs.

Several studies have found that high yield PRFs from screening panoramic radiographs had little or no influence on the surgical or prosthetic treatment plan of the patient, suggesting the practice should be discontinued. In the studies reviewed below,
the terminology used for the panoramic radiographic surveys undertaken encompassed a variety of terms to describe the purpose of the radiograph as either “pre-treatment,” “routine,” or “screening.” It was not always clearly indicated if the panoramic radiograph was taken prior to a clinical examination or in some cases with or without a clinical examination in the reviewed studies listed in Table 7. In the truest sense of the word, a “screening” radiograph implies the panoramic image was taken prior to a history and clinical exam of the patient (i.e. pre-treatment)\(^{12}\). A “routine” radiograph is one in which a clinical exam may have been completed (but not necessarily) and the image was still taken because the patient was edentulous or a certain interval of time had passed. Nonetheless, the underlying implication is that a routine panoramic image is used for screening purposes, and the two terms are often used interchangeably.

**Table 7: Reports on the distribution of positive radiographic findings in panoramic radiographs that assessed the impact on patient treatment**

<table>
<thead>
<tr>
<th>Reports*</th>
<th>Distribution</th>
<th>Radiographs (n)</th>
<th>Radiographs with PRFs</th>
<th>PRFs impacting treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>White &amp; Weissman 1977 (USA)(^ {70})</td>
<td>3059</td>
<td>N/A -Abstract only</td>
<td>3 (0.1%)</td>
<td></td>
</tr>
<tr>
<td>White et al., 1984 (USA)(^ {64})</td>
<td>117</td>
<td>8</td>
<td>8 (6.8%) (a)</td>
<td></td>
</tr>
<tr>
<td>Lloyd &amp; Gambert 1984 (USA)(^ {68})</td>
<td>86</td>
<td>7</td>
<td>0 (0%)</td>
<td></td>
</tr>
<tr>
<td>Keur 1986 (Australia)(^ {14, 72})</td>
<td>1135</td>
<td>692</td>
<td>386 (34%) (b)</td>
<td></td>
</tr>
<tr>
<td>Garcia et al., 1987 (USA)(^ {66})</td>
<td>33</td>
<td>13</td>
<td>0 (0%) (c)</td>
<td></td>
</tr>
<tr>
<td>Lyman &amp; Boucher 1990 (USA)(^ {69})</td>
<td>150</td>
<td>1 (d)</td>
<td>1 (0.67%)</td>
<td></td>
</tr>
<tr>
<td>Kogon et al., 1991 (Canada)(^ {59})</td>
<td>51</td>
<td>33</td>
<td>2 (3.9%)</td>
<td></td>
</tr>
<tr>
<td>Ansari 1997 (Jordan)(^ {71})</td>
<td>286</td>
<td>N/A -Abstract only</td>
<td>3 (1.0%)</td>
<td></td>
</tr>
<tr>
<td>Bohay et al., 1998 (Canada)(^ {15})</td>
<td>205 (e)</td>
<td>140</td>
<td>17 (8.3%) (f)</td>
<td></td>
</tr>
<tr>
<td>Masood et al., 2007 (USA)(^ {67})</td>
<td>308</td>
<td>131</td>
<td>5 (1.6%) (g)</td>
<td></td>
</tr>
</tbody>
</table>
only two of the PRFs (2 root fragments) were identified from the screening radiograph, but another six findings were identified clinically: subcondylar fracture (1); mandibular atrophy (3); and planned surgery (2).

- the high rate of “treatment impact” is because all root fragments or unerupted teeth were “referred” to oral surgeon for evaluation and treatment as necessary; it was not reported how many of the lesions referred actually had surgical intervention.

- treatment recommended for 2 patients (6%) each of whom had 1 root tip, the patients did not follow recommendation and radiographic appearance of the abnormality remained stable over 10 year study period

- low number of PRFs (1), because any patient whose clinical examination suggested the need for an individualized radiographic prescription (enlarged maxillary tuberosities, swellings, retained roots or symptoms of pain, numbness or other abnormal sensations) were excluded.

- data reported is on the 205 screening patients, as there were 170 patients who received selective panoramic radiographs.

- of the 17 patients needing treatment after screening panoramic radiograph, nine of the PRFs are seen clinically, leaving only 8 (or 4%) who were treated for PRFs that were disclosed only by screening panoramic radiographs.

- 5 root fragments (out of 39) required a treatment modification prior to denture fabrication.

In the research examining PRFs identified in screening panoramic radiographs, the most common findings in no particular order were typically: idiopathic osteosclerosis (also known as dense bone islands), root fragments, unerupted/retained teeth and foreign bodies (most notably amalgam tattoos)\textsuperscript{13-15, 18, 29, 60, 67, 69, 72-74}. None of these common PRFs should be considered as pathological, unless they involve an infection or cyst\textsuperscript{15}. Clinicians tend to overestimate the pathological potential of unerupted teeth, which leads to an overestimation of their clinical significance as a PRF\textsuperscript{75}. However, if root fragments or unerupted teeth are not on or very near the alveolar ridge surface, they need not be surgically removed. They can be safely left in place to preserve bone or decrease morbidity, especially when they are small (<4-5mm) or uninfected with no periapical radiolucencies, without affecting denture fabrication\textsuperscript{18, 60, 69, 73, 76, 77}.

Additionally, according to surgical guidelines pertaining to impacted tooth removal, contraindications include medically compromised individuals, which is often the case in the edentulous population\textsuperscript{76}. Furthermore, the surgical guidelines state if a tooth has been retained in the alveolar process for many years without periodontal disease, caries, or cystic degeneration, it is unlikely that these unfavorable sequelae will occur; therefore in a patient over 35 years of age with an impacted tooth that shows no signs of disease and that has a detectable layer of overlying
bone, the tooth should not be removed\textsuperscript{76}. The presence of foreign bodies or other common high yield PRFs identified such as retained roots or impacted teeth do not necessarily call for an alteration in the treatment plan, thus diminishing the net benefit to the patient\textsuperscript{69}.

To further substantiate reasons against screening radiography it has been pointed out that within the medical field, routine screening of selected population groups generally offers little value and has been abandoned\textsuperscript{18}. There are a few exceptions however, such as screening mammography\textsuperscript{18}, although, there is even controversy about this modality because of the high numbers of false positives (FPs) that lead to over-diagnosis and overtreatment in 30\% of women\textsuperscript{78}. According to this Cochrane review, this means for every 2000 women screened over 10 years, one will avoid dying of breast cancer while 10 healthy women will be treated unnecessarily with lumpectomies and mastectomies and undergo the psychological distress associated with the FP diagnosis and treatment arising from the screening\textsuperscript{78, 79}. Nevertheless, screening mammography remains the most commonly performed procedure for breast cancer detection due to the high incidence of breast cancer worldwide and its associated reduction of cancer mortality by 15\%\textsuperscript{78, 80}.

The ADA’s 2006 radiation guidelines state that dentists should not take screening panoramic radiographs for detecting calcified carotid artery artheromas (CCAAs) or other occult pathoses in asymptomatic patients\textsuperscript{2, 22}. Studies investigating PRFs using panoramic imaging show extremely low percentages of 0.1 – 4.8\%\textsuperscript{62} and 0 – 8.3\% of PRFs requiring treatment, with one exception at 34\% (Table 7)\textsuperscript{15, 18, 59, 62, 64, 66–71}. Screening for bone pathoses ignores this low prevalence of asymptomatic, occult lesions, reducing the diagnostic value of a screening image when taken without a specific reason,\textsuperscript{16, 22, 27} and does not consider the burden associated with possible FP findings.
Although the panoramic radiograph has many advantages compared to a PA and FMS for edentulous patients, the diagnostic accuracy has been criticized. In a comparative study of panoramic screening versus PA and FMS of edentulous patients, the panoramic radiographs had a higher incidence of false positives (FPs) and false negatives (FNs) and failed to show one-fourth of the radiographic findings that were identified when PAs were used\textsuperscript{18}. In another study involving dentulous patients, when a panoramic radiograph was taken in addition to BWs and PAs, 57\% of the patient’s received no added value from the panoramic radiograph and 65.3\% of the panoramic radiographs had no relevance to treatment\textsuperscript{3}. This, in conjunction with the high rate of positional errors found within panoramic radiographs diminishes their value as a screening tool when no apparent clinical indication exits.

A final argument against screening panoramic radiographs relates to the education of dentists. Dentists generally prescribe radiographs according to personal routine or the way they were taught in dental school\textsuperscript{9,17}. Dental graduates are likely to model their practices on what they were taught and what they observed in school. The effects of suboptimal practices learned at school such as not adhering to guidelines, are multiplied when graduates enter practice and provide service to thousands of patients; so a valuable way forward is to educate the undergraduate dentists regarding current regulatory guidelines and selection criteria so they become integrated into their daily practice\textsuperscript{9,17}.

In summary, the main arguments against the use of routine screening of edentulous patients with a panoramic radiograph prior to complete denture fabrication include: the ethical and legal requirement to follow evidence based guidelines; the high yield of PRFs is generally inconsequential and does not affect the prognosis, health and/or management of the patient; the hopes of identifying an asymptomatic, occult pathoses in screening radiographs is not an
adequate justification due to their overall low prevalence; the fact that selection criteria reduces the need to expose patients to unnecessary radiation with a minimal risk of missing a radiographic finding that could affect the treatment outcome; the decreased ability of panoramic radiographs to identify periapical lesions and the increased rate of FNs and FPs compared to a intraoral radiograph prescribed via selection criteria; and the importance of setting a good example and appropriately educating dental students to engrain evidence based habits.

1.4.2 Arguments For Screening Panoramic Radiographs

The first commonly cited defense of the use of screening panoramic radiographs as part of treatment planning for CRDP is the high yield of PRFs identified in the edentulous population, most of which are asymptomatic and thus, unexpected\(^{13-15, 18, 72, 73, 77, 81}\). In one review article, there were 16 studies identified between 1970-1994 that considered the high yield of PRFs as support in and of itself for routine screening of edentulous patients\(^{18}\). This high yield of PRFs is generally found in 16-50% and as high as 61%\(^{18, 28, 60, 69}\) of edentulous patients. A 2011 study concluded that a screening panoramic radiograph for an edentulous patient prior to denture fabrication is “critical” and should be mandatory because of all the PRFs identified that would have otherwise gone unnoticed\(^{13}\). This high yield of PRFs could be more beneficial than the potential stochastic effects linked to low-dose ionizing radiation emitted during a panoramic radiograph\(^{14, 72, 82}\).

As explained previously, depending on the panoramic radiographic machine, there can be a large variation in effective dose, which equates to \(\approx 1-5\) days additional background radiation\(^{3, 12}\). These dosages have been extrapolated to an estimated lifetime risk of developing a fatal malignancy of 0.17-1.9/million\(^{3, 6, 7, 12, 14, 18}\). Furthermore, tissue reaction effects and genetic effects are not considered issues during dental radiography because the dose is too low and the
gonads are typically well-protected. Thus, some authors believe that the process of identifying unexpected PRFs and informing the patient outweighs the potential detriment of the ionizing radiation to the patient. This argument is corroborated not only with PRFs that affect treatment, but also for clinically significant lesions that carry a high morbidity or mortality rate associated with them. For example, a keratocystic odontogenic tumour, previously known as an odontogenic keratocyst, was discovered by a screening panoramic radiograph in an edentulous patient prior to complete denture fabrication. Keratocystic odontogenic tumours are the third most common odontogenic cyst (when classified as a cyst rather than a tumour), constituting 3-11% of all jaw cysts. It is of great concern to clinicians because of its high recurrence, aggressive behavior, and occasional association with nevoid basal cell carcinoma syndrome (Gorlin syndrome) and thus is considered the most dangerous “dental” cyst. Ten percent (10%) of KCOT’s occur in edentulous patients and can go unidentified as they seem to follow the path of least resistance growing into the bone marrow, rather than creating an expanding periosteal bone formation, which can potentially lead to a jaw fracture as a result of asymptomatic hollowing of the jaw. Both an individual in whom this lesion was found and the treating clinician would argue that the clinical significance of detecting this lesion with a screening radiograph outweighs the potential stochastic risks associated with low-dose ionizing radiation.

Other odontogenic cysts are usually asymptomatic and odontogenic tumours may also be asymptomatic, and are therefore commonly detected only with screening radiographs. Ameloblastomas, which can be very aggressive, are the second most common odontogenic tumour (12% of odontogenic tumours) that can be identified as an incidental or “chance” radiolucent finding on panoramic radiographs. On rare occasions, ameloblastomas have given
rise to distant metastasis making them very clinically significant to identify early\textsuperscript{88}. The most common malignant primary bone tumours affecting the jaws include osteosarcoma, Burkitt’s lymphoma and multiply myeloma, while secondary or metastatic tumours to the jaws are rare in contrast to the remainder of the skeleton\textsuperscript{89}. Osteosarcoma, for example, has a statistically low incidence of occurrence, (estimated to occur in 0.07 patients/100,000\textsuperscript{90,91}) but it has a substantial clinical significance with a five-year survival rate of only 20.3\%-30\%\textsuperscript{90}. Although the prevalence of these morbid PRFs is low, the lesions, if discovered early can be clinically significant to the individual affected and may save lives or decrease morbidity. Given the high recurrence rate, destructive behavior and morbidity or mortality associated with some odontogenic lesions and malignancies, a patient may decide the low stochastic risk associated with radiation from modern day digital equipment is worth the risk of identifying a clinically significant PRF early on.

As discussed earlier, despite some controversy, screening of selected populations is also seen in medicine with the use of mammograms because of the clinical significance associated with breast cancer. Mammography is used as a screening tool to detect breast cancer, which is the most common cancer and also the leading cause of cancer mortality in women worldwide\textsuperscript{80,92-94}. The highest incident rates are in Europe and NA\textsuperscript{80}, with American woman having a lifetime risk of developing breast cancer of 12.38\% (1 in 8)\textsuperscript{92}. Depending on socioeconomic status, there is a five-year survival rate of between 40\% for low income and 80\% for high income individuals with breast cancer\textsuperscript{92}. Multiple studies have shown a reduction in breast-cancer mortality of between 13-50\% with screening mammograms\textsuperscript{80,95-97}, with an overall 15\% reduction in mortality when meta-analysis was completed\textsuperscript{96}. The ultimate aim of screening is to advance the time of diagnosis so that prognosis can be improved by earlier intervention, which can extend the time
between diagnosis and death, even if the screening does not confer any benefit. This is essentially how many dentists must justify their radiographic prescription protocols, with a reported 42% and 53% of dental practitioners in the UK and NA, respectively, using routine panoramic radiographs to “screen” the jaws for clinically unsuspected pathoses despite the guidelines advising against such actions.

Others contend, at the minimum, that the panoramic screening radiograph as a baseline or initial reference could be of some value to follow-up on the PRFs identified such as root tips and impacted teeth, even if no clinically significant PRF is identified or treatment intervention is required initially.

Closely related to identifying unsuspected PRFs and possible clinically significant occult pathosis is the interrelated fear of litigation. The idea of potentially missing a serious lesion, in addition to disclosing the presence of asymptomatic PRFs such as root fragments, unerupted teeth, or cysts to avoid possible litigation, are other reasons some clinicians feel the need for screening panoramic radiographs. The argument is that full disclosure is required so the patient can give informed consent regarding their treatment, freeing the dentist of liability should dental complications arise in the future requiring surgical intervention or modification to the CRDP. The assumption is that full disclosure and avoidance of litigation can only be obtained by the use of screening radiographs to identify “hidden,” asymptomatic radiographic findings. The fear of litigation, along with a desire to do no harm while potentially providing information that could improve the prognosis of treatment for a patient by identifying a morbid PRF early on, can also be argued to be clinically significant to the practitioner, and thus another reason why such high percentages of dentists still perform screening radiographs in NA and UK.
The idea of providing full disclosure to obtain informed consent ties directly to fully describing all risks and benefits of the treatment proposed. This includes the risks and benefits associated with a screening panoramic radiograph, which would allow the patient to make an informed decision about the associated low risks of stochastic effects versus the low chance of potentially detecting a clinically significant PRF that could affect denture fabrication (discussed below) or enable earlier intervention with a potentially morbid finding. It is the compelling claim of individuality and autonomy that gives the patient the right to make their decisions about health and bodily fate\textsuperscript{63,99}. Most litigation about patient autonomy now occurs over care-provider’s non-disclosure of information, analyzed as an issue of professional negligence\textsuperscript{63}. Part of a clinician’s duty to avoid professional negligence and litigation is to provide the patient sufficient information to allow an informed decision\textsuperscript{63}. For example, a surgical intervention is competently recommended and competently carried out, but the clinician fails to disclose a low-probability risk of a complication, such as the possibility of an allergic reaction to the anesthetic. If an allergic reaction occurs, the patient could suffer, which increases the risk of a malpractice charge against the doctor for failure to secure informed consent\textsuperscript{63}. The fear of litigation discussed by some clinicians could follow a similar argument, whereby an intervention, such as a screening radiograph, is not made and the chance of finding a low prevalence PRF is missed. In both cases, a low chance incidence occurred, whereby if the patient had been informed, they could make their choice as to whether to proceed with surgery in the first scenario, or the screening radiograph in the second scenario. Thus, the issue as to screen or not to screen could be argued in legal terms to remain to the autonomy of the informed patient.

Lastly, from a technical standpoint of denture fabrication, it has been argued that for good denture stability and retention, the remaining alveolar process must be free of all intrabony and
soft tissue anomalies\textsuperscript{13}. This assumes these intrabony/soft tissue anomalies would not be found by a comprehensive clinical examination and would require removal by surgical intervention once identified by a screening panoramic radiograph.

Overall, the reasons reported to substantiate screening panoramic radiographs can be summarized by stating that there is generally a high yield of PRFs found in the edentulous patient that, once identified, allow the patient to be fully informed of treatment options and lessen the dentist’s risk of litigation for any potential future issues relating to these unexpected (occult) findings. The knowledge gained by identifying the PRFs and the ability to obtain a “fully” informed consent and fabricate a CRDP on supporting-tissues free of radiographic findings is the benefit that outweighs the risk associated with low-dose radiation. Additionally, the chance of identifying a clinically significant lesion that gives an individual a better overall prognosis due to early identification and intervention could be seen to be of more value than the low risk associated with radiation from a screening panoramic radiograph.

1.5 Rationale for this Research Project

The rationale for this study are best described as follows:

a) it is the first to review digital panoramic images, which may enhance the ability to identify different radiodense lesions and to assess the clinical significance of positive radiographic findings (PRFs) (i.e. effect on treatment);

b) the results of this study will allow us to weigh-in on the discordant viewpoints in the literature surrounding the issue of screening panoramic radiographs for edentulous patients with the advantages that come with reviewing digital images;
c) additionally, the results could inform future training and/or operations that can improve the way radiographs are interpreted at the UBC Oral Health Centre, providing an in-house quality assurance that may be applied to other institutions, and
d) finally, the findings of the quality assurance aspect of this study can help to ensure that the next generation of dental graduates from UBC are aligned with appropriate radiographic protocols for edentulous patients

1.6 Objectives and Hypotheses

The primary objective of this study was to identify findings on digital panoramic radiographs of edentulous patients to determine if they impacted patient management prior to fabrication of complete dentures. The primary null hypothesis is that the routine use of digital panoramic radiograph will not yield “clinically significant findings” that influence the treatment of edentulous patients prior to conventional CRDP fabrication.

Secondarily, a quality assurance assessment of panoramic radiographs made for denture patients at UBC was completed by comparing two student groups, in 2\textsuperscript{nd} year Introduction to Prosthodontics (IPROS) and 3\textsuperscript{rd}/4\textsuperscript{th} year Integrated Clinical Care (ICC), regarding: i) radiographic interpretations completed, ii) radiographic interpretation errors (RIEs) made, and iii) positional errors detected. The secondary null hypotheses are that there are no differences between the prosthodontics course (IPROS) and the general dental integrated care clinic in the areas examined: i) radiographic interpretations completed, ii) RIEs made and, iii) positional errors detected.
Chapter 2: Materials and Methods

2.1 Ethical Approval

Ethics approval was obtained (H12-03685) from UBC Clinic Research Ethics Board (CREB) on Jan 23rd, 2013, prior to commencing this retrospective study and reviewing patient charts. In case there was a need to re-access patient records to confirm data, ethics approval was renewed in 2014.

2.2 Parameters and Definitions Used

Prior to describing the methods used in this study, some commonly used terms will be reiterated or elaborated upon and the rationale for the methods employed will be discussed.

Based on a review of previous studies’ methodologies (Table 7), it was evident that a variation exists in nomenclature surrounding the timing of the panoramic radiograph: terms used, seemingly interchangeable, include pre-treatment, routine, or screening. It appears that the common underlying assumption is that a routine panoramic image is used for screening purposes. It is important to reiterate that a screening radiograph is accurately defined as an image made regardless of the presence or absence of clinical signs and symptoms and without a clinical examination\textsuperscript{12}.

At UBC, the protocol in all clinics, including the two courses compared here, involves a history and an initial clinical examination of the patient before any radiographs are requested, although currently, panoramic radiographs are routinely taken of edentulous patients after confirming that no previous panoramic images are available. That being clarified, the terms screening and routine are used interchangeably within the context of this study.
“Prior” to complete denture fabrication indicates that the screening panoramic radiograph was made at an appointment before the making of a new conventional CRDP commenced. This is generally at the initial examination or treatment plan discussion appointment for the students in ICC or before being seen by a student in IPROS.

“Conventional” as it relates to CRDP means that the prosthesis is not implant-assisted or supported.

In order for a screening panoramic radiograph to be considered “diagnostically acceptable” in this study, a clinically relevant definition was utilized, similar to the NRPB’s definition. The three categories of “excellent,” “diagnostically acceptable,” and “unacceptable,” were not used because the category of “excellent” has been questioned by some authors, suggesting it is not clinically feasible\textsuperscript{20, 21}. In the current study, the intended purpose of the screening radiograph was assumed to be visualization of the edentulous arches to aid in CRDP fabrication. Thus, panoramic radiographs were deemed to be either diagnostically acceptable or unacceptable, similar to the NRPB. Additionally, in our study, a panoramic radiograph was considered “diagnostically acceptable” if the edentulous denture-bearing area of the maxilla and mandible were visible despite positional errors or exposure errors. Similarly, “unacceptable” meant the panoramic radiograph needed to be retaken to be of any diagnostic value.

With respect to radiographic terms describing the PRFs, the radiodensity or shade of a lesion observed is usually described in one of three ways: radiolucent, radiopaque or mixed\textsuperscript{45}. A radiolucency is the black or darker area on a conventional radiograph and represents an absence of the bone type normally found for a particular anatomical site. It is suggestive of an osteolytic process when present in bone\textsuperscript{45}. A radiopaque lesion appears white on a conventional radiograph.
and represents an excess of mineralized tissue. Although many normal structures, such as teeth, the jaw bones, skull base and cervical vertebrae are radiopaque, the terms radiopacity or radiopaque lesion are generally applied only to those PRFs with excessive deposition of mineralized tissue suggestive of pathoses\textsuperscript{45}. Mixed lesions (ML) are described as white area(s) within a black area\textsuperscript{45}.

Extragnathic (EN) lesions were included as a category because when a panoramic radiographic is taken, the clinician must evaluate the full data set or entire image, not just the areas of interest, to ensure satisfaction of search (SOS). Extragnathic findings can affect the overall health and well-being of the patient (i.e. CCAA) and therefore the clinician needs to be prepared to refer depending on the differential diagnosis (DDx) of any suspected EN lesions and patient’s medical and dental histories\textsuperscript{100}. Extragnathic lesions are not exclusive to RO, RL or mixed lesions (ML); rather, they are PRFs not found within the bone of the maxilla or mandible. They are generally calcified structures found within soft tissues, thus giving them a radiopaque/white appearance. \textbf{Table 8} provides several examples of each category.
Table 8: Examples of identified radiopaque (RO), radiolucent (RL), mixed (ML) and extragnathic (EN) lesions reported from panoramic radiographs

<table>
<thead>
<tr>
<th>Lesion Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Radiopacity</strong></td>
<td>idiopathic osteosclerosis (IO) [a.k.a. dense bone island (DBI)], condensing osteitis (CO) [a.k.a. sclerosing osteitis], root fragment, fractures, foreign bodies (amalgam tattoo, residual cement or endodontic sealer), mucosal antral pseudocyst, sinus mucositis, osteoma, bone sequestra</td>
</tr>
<tr>
<td><strong>Radiolucency</strong></td>
<td>cyst (nasopalatine, residual, dentigerous), lingual bone defect (a.k.a. Stafne’s bone defect), keratocystic odontogenic tumour (a.k.a. odontogenic keratocyst), neoplasms or secondary metastasis</td>
</tr>
<tr>
<td><strong>Mixed Lesion</strong></td>
<td>root tip, impacted/unerupted tooth, odontomas (compound/complex)</td>
</tr>
<tr>
<td><strong>Extragnathic</strong></td>
<td>CCAA, calcified lymph nodes (LN), sialolith (parotid or submandibular), tonsillolith</td>
</tr>
</tbody>
</table>

The term “clinically significant finding(s)” in this study is synonymous or interchangeable with significant radiographic finding(s) and relates to radiographic findings or other abnormalities affecting the management of patients, including referrals. This definition was utilized based on the concept of “net benefit,” which implies that a PRF affects the management or prognosis of a patient. As stated previously, a PRF is deemed a net benefit to the patient if it represents a pathosis such as infection, malignancy, destructive tumour/cyst and/or it poses a health risk and affects denture fabrication.

2.3 Study Population

This retrospective study was based on a convenience sample that included patients who had both a panoramic radiograph and complete upper and lower dentures made at UBC between September 1st, 2006, when digital panoramic radiography was implemented, and December 31st, 2012, after which data collection began. Patients who had a screening panoramic radiograph
taken with the ProMax Planmeca digital panoramic machine (Helsinki, Finland) were identified via an electronic health record (EHR), Axium™. From these 3,306 records, 200 radiographs of edentulous patients also receiving CRDP were identified from the database at the UBC Oral Health Centre. However, the number was reduced to 169, as 31 records were excluded (see section 2.3.1). All 169 included digital panoramic radiographs were evaluated in a dim room on a medical grade diagnostic gray scale (MGDG) monitor.

The sample of 169 edentulous, digital, panoramic radiographs was split into two groups based on the type of dental student who reviewed the panoramic radiographs: 2nd year students in the prosthodontics course (IPROS) versus (vs.) 3rd and 4th year students in the general dental integrated care clinic (ICC). We sought to identify differences between: i) radiographic interpretations completed, ii) radiographic interpretation errors (RIEs) made with respect to PRFs and, iii) positional errors detected. Comparison of the groups and statistical analysis were completed (see Section 2.6). There were 85 ICC and 84 IPROS panoramic radiographs.

2.3.1 Exclusion Criteria

In this study, 31 out of 200 identified patient records were excluded for the following reasons: clinical crowns present (19), implants present (2), an analog panoramic radiograph was scanned in electronically (6) or there was no digital panoramic radiograph present (4).

Nineteen panoramic radiographs were excluded because, upon review, there were teeth with clinical crowns still present at the time of the screening radiograph. Thus, the patient was not currently edentulous and did not meet the inclusion criteria.

Similarly, four panoramic radiographs were excluded because implants were present in the mouth. It was decided the panoramic radiographs could be used to justify the follow-up of
the present implants and that the prosthesis to be fabricated would be an implant-assisted CRDP, not a “conventional” denture. Additionally, one justification for taking a screening panoramic image is to plan and inform the patient of possible surgical augmentations required for implant placement. Panoramic radiographs are sufficient to evaluate available bone height and are safe for surgical placement if at least 2mm of bone is above the mandibular canal\textsuperscript{7,82,102}, once again meaning that such images did not fit the definition of a screening radiograph.

Ten additional screening panoramic radiographs were excluded either because the image was not originally digital (6), or there was only an analog panoramic radiograph present (4).

Based on these exclusions, there were 169 remaining digital, screening panoramic radiographs of edentulous patients seeking treatment for a conventional CRDP at UBC Oral Health Centre.

2.4 Pilot Project and Data Collection

Initially, 25 screening panoramic radiographs from the 169 identified records were randomly selected using a random number generator (Research Randomizer\textsuperscript{TM}) in order to calibrate the primary reviewer (RK) and ascertain that all relevant data were collected from the EHR and cross-referenced with the paper chart. Each patient’s age and sex were recorded. The PRFs were subdivided into 4 categories [radiopaque (RO), radiolucent (RL), mixed lesion (ML) and extragnathic (EN) lesions] (Table 11 in Results 3.2) as identified by the “experts” and “students,” defined below. Positional errors were subdivided into 8 categories (right and left head shift, right and left head rotation, chin up, chin down, improper tongue position and “other”) (Table 15 in Results 3.3), and reported as described by the experts and students. Whether or not the panoramic radiograph was interpreted and of diagnostic quality was
evaluated by the expert. The impact the PRFs identified by the students had on treatment was
determined with a chart audit.

All 25 initial radiographs and the data collected by the primary investigator were then
reviewed with the Oral Maxillofacial Radiologist (OMFR), Dr. David MacDonald. Henceforth,
the term “expert(s)” refers to the primary investigator and/or the OMFR, and “students” refer to
IPROS or ICC cohorts.

Subsequently, the remaining digital panoramic radiographs were also reviewed in a dimly
lit room on a MGDG monitor. Once the pertinent data were collected (age, sex, number of
radiographs interpreted by the students, diagnostic acceptability of the panoramic radiographs,
PRFs and positional errors detected by the experts and students) from all 169 charts, the data
were analyzed (Section 2.6 and “Results”). The OMFR was also consulted anytime there was
uncertainty about a PRF.

2.5 Internal-rater Reliability

Lastly, 20 charts were randomly selected after review with the same random number
generator (Research Randomizer) and re-checked by the OMFR to assess inter-rater reliability
by using observed proportion of agreement (Section 2.6). Each of the randomly selected
radiographs was blindly compared in 5 categories [RO, RL, ML, EN and Stylohyoid Ligament
(SHL) calcifications] to determine the proportion of agreement between the primary investigator
and the OMFR.

2.6 Post-Hoc Power Analysis

A post hoc power analysis was used to help understand the observed results by
calculating the effect size observed between the two groups. This is also a compromised
power analysis because it is based on a restricted sample size or sample size of convenience (http://www.vchri.ca/i/pdf/powerandsamplesize.pdf). Using Lehr’s basic formula to obtain a sample size, it can re-arranged to determine the standard difference. Selecting a type I error or an $α=0.05$, power ($1-\beta$) of 80% and a sample size, $n=84$, will give us the standard difference ($\Delta$). Lehr’s basic formula is below http://www.vanbelle.org/chapters%5Cwebchapter2.pdf):

$$n = \frac{16}{\Delta^2}$$

Where

$$\Delta = \frac{\delta}{\sigma}$$

and $\delta$ is the target difference (difference in means) and $\sigma$ is the standard deviation. Using this formula and entering the specified values indicated above, the standard difference ($\Delta$) is 0.44. Additionally, for a two-sided t-test to compare two population means using a more exact formula below confirms Lehr’s “rule of thumb” obtaining a d value of 0.44:

$$n = \frac{2(z_{1-\alpha/2} + z_{1-\beta})^2}{\left(\frac{\mu_0 - \mu_1}{\sigma}\right)^2}.$$ 

Similar to the standard difference ($\Delta$) in the above formula, d is the effect size, otherwise known as the differences in means. The effect size (d) is given by the following formula:

$$d = \frac{|\mu_1 - \mu_2|}{\sigma}.$$
Using the standard difference obtained in the above formula for d, we see only 81 samples would be required for a medium effect size of 0.44 (see below).

\[
  n \geq 2x(1.96 - (-0.84))^2/(0.44)^2 \\
  n \geq 2x(2.8)^2/(0.1936) \\
  n \geq 15.68/0.1936 \\
  n \geq 80.99 \\
  n \geq 81 \text{ patients per group}
\]

Similarly, if we plug in 84 for “n”, an effect size value of d=0.43 is achieved.

Cohen suggested that d=0.2 be considered a 'small' effect size, 0.5 represents a 'medium' effect size and 0.8 a 'large' effect size\textsuperscript{105}. In Cohen's terminology, a small effect size is one in which there is a real effect -- i.e., something is really happening in the world -- but which you can only see through careful study. Conversely, a 'large' value of d, tells us that the difference between these two groups is large enough and consistent enough to be really important and usually indicates a stronger effect (\url{http://staff.bath.ac.uk/pssiw/stats2/page2/page14/page14.html}, \url{http://en.wikipedia.org/wiki/Effect_size}). Thus, in order to be able to detect a “medium” size difference between the groups (d=0.44), with a power of 80% and an \(\alpha=0.05\), the calculated sample sizes required would be 84 and 81 using both formulas, respectively. The restricted or convenient sample size in this study was 84 and 85 for each group.

2.7 Data Analysis

A p-value of 0.05 was considered to be of statistical significance for all parameters and statistical analysis was completed using Microsoft Excel for Mac (2012).

The 2-sample t-test was performed to compare means between two sample populations with respect to the patient ages, radiographic interpretations completed by students, errors made
by students with respect to PRFs [known as radiographic interpretation errors (RIEs)], and positional errors missed by students [known as positional error misidentifications (PEMs)] between IPROS and ICC student groups. Additionally the 2-sample t-test was used to compare the total number of panoramic radiographs with positional errors detected between experts and students, and between ICC and IPROS.

Whenever categories had to be combined (i.e. RO, RL, ML and EN) to total the PRFs in order to have sufficient data for a statistical test, the Bonferroni corrected t-test was used. This statistical test allows one to make comparisons between 2 groups by pooling different categories\(^{106}\). This avoids the concern that by combining multiple comparisons, one may erroneously conclude statistical significance by chance simply from having carried out many tests or comparisons. The Bonferroni correction adjusts the significance level and safeguards against the inflated chance of type 1 error at the cost of reduced power to detect a significant or real difference. This was the situation when comparing the total number of PRFs and positional errors detected by the experts for each of the ICC and IPROS patient pools.

For inter-rater reliability between the experts (Drs. Kratz and MacDonald) in order to strengthen the internal validity of the study, the observed proportion of agreement (percent agreement) was used\(^ {103}\). An agreement is any category of the radiographic evaluation where the two experts matched completely and it relates to the consistency between two observers. To recap, the five categories used for the observed proportion of agreement on the 20 randomly selected panoramic radiographs included RO, RL, ML, EN and SHL calcification.

A Confidence Interval (CI) at 95% was used to infer the number of PRFs expected to be found on the screening panoramic radiographs and the percentage of identified PRFs expected to affect treatment for the edentulous population attending UBC. The CI is used to find the range in
which the true value will be found 95% of the time\textsuperscript{103}. Additionally, the CI was used to
determine the expected true value of observed proportion of agreement or reliability between the
experts.

2.8 Summary of Methods

Figure 8 below is a summary of the methods used in this retrospective study.

Figure 8: Methods overview
Chapter 3: Results

3.1 Demographics and Panoramic Radiograph Interpretations Completed for ICC and IPROS Student Groups

Of the total sample (n = 169), there were 88 female (52%) and 81 male (48%) patients in the panoramic study population. The average age of participants was 70.7 yrs (range: 25 – 97 yrs). The records reviewed were categorized into two groups based on the student population interpreting the panoramic radiographs – ICC and IPROS. The ICC sample was 85, while there were 84 panoramic radiographs interpreted in the IPROS group. There was a statistically significant difference (p = 0.00069) in patient age and in the number of panoramic radiograph interpretations completed (p = 0.00014) between the two student groups, with an older patient population treated in ICC and a higher proportion of images interpreted in IPROS (Table 9).

<table>
<thead>
<tr>
<th>Feature</th>
<th>ICC (n= 85)</th>
<th>IPROS (n = 84)</th>
<th>TOTAL (n = 169)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female : Male</td>
<td>46: 39</td>
<td>42: 42</td>
<td>88: 81</td>
</tr>
<tr>
<td>Age (avg ± SD) yrs</td>
<td>73.8 ± 11.9</td>
<td>67.5 ±11.8</td>
<td>70.7 ± 12.2</td>
</tr>
<tr>
<td>Interpreted Radiographs</td>
<td>65 (76.5%)</td>
<td>81 (96.4%)</td>
<td>146 (86.4%)</td>
</tr>
</tbody>
</table>

i) p = 0.00069 (2-tailed t-test); significant statistical difference in age between ICC and IPROS

ii) p = 0.00014 (2-tailed t-test); significant statistical difference in panoramic radiograph interpretations completed between ICC and IPROS

3.2 Positive Radiographic Findings (PRFs) and Effect on Treatment

Of the 169 digital panoramic radiographs reviewed by the experts, 101 (60%) had positive radiographic findings (PRFs). Sixty-eight (40%) of the panoramic radiographs had zero PRFs, 61 (36%) had only 1 PRF, and 40 (24%) had more than 1 PRF. There was a total of 165 PRFs identified by the experts: 92 (56%) RO, 56 (34%) EN, 13 (8%) ML, and 4 (2%) RL lesions (Tables 10 and 11). One-hundred sixty five PRFs equates to 0.98 PRFs per screening
panoramic radiograph (165/169). The 95% CI was (0.81, 1.42), which indicates that in the population attending the UBC Oral Health Centre for CRDP, the true value of PRFs is between 0.81 and 1.42/edentulous patient.

Table 10: Number of panoramic radiographs with positive radiographic findings (PRFs) identified by the experts and the effect on treatment as determined by students

<table>
<thead>
<tr>
<th># of “Pans” with...</th>
<th>ICC (n =85)</th>
<th>IPROS (n = 84)</th>
<th>TOTAL “Pans”</th>
<th>TOTAL PRFs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiopacity</td>
<td>29</td>
<td>37</td>
<td>66</td>
<td>92</td>
</tr>
<tr>
<td>(includes roots, foreign bodies counted below)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiolucency</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Mixed Lesion</td>
<td>5</td>
<td>6</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td>Extragnathic</td>
<td>19</td>
<td>22</td>
<td>41</td>
<td>56</td>
</tr>
<tr>
<td>DDx of CCAA</td>
<td>14</td>
<td>16</td>
<td>30</td>
<td>44</td>
</tr>
<tr>
<td>Foreign bodies</td>
<td>6</td>
<td>9</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Retained root(s) or root fragment(s)</td>
<td>14</td>
<td>17</td>
<td>31</td>
<td>37</td>
</tr>
<tr>
<td>Unerupted/impacted tooth/teeth</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Roots and Teeth not treated</td>
<td>14</td>
<td>18</td>
<td>32</td>
<td>N/A</td>
</tr>
<tr>
<td>Roots and Teeth treated</td>
<td>2</td>
<td>2</td>
<td>4*</td>
<td>N/A</td>
</tr>
</tbody>
</table>

- unit of measure is the panoramic radiograph (i.e. the patient) and not the number of PRFs, so these numbers do not always equal the total PRFs as some patients had more than 1 PRF (except in column 5).
- “Pans” = panoramic radiograph; DDx = differential diagnosis; CCAA = Calcified Carotid Artery Atheroma
* 4 out of 6 patients were treated for root tips/fragments and an impacted tooth, the other 2 patients had referrals for osteophytes on spine (risk of arthritis) and a suspected CCAA (risk of stroke).

Only six positive radiographic findings identified by students at the time of the initial panoramic radiograph interpretation had an impact on the treatment management of the patient prior to fabrication of the conventional CRDP (Table 11). The 95% CI was (0.8%, 6.3%), which indicates that the true value of a PRF in the edentulous population attending the UBC Oral Health Centre that will affect treatment is between 0.8% and 6.3% of PRFs. According to the EHR, the six PRFs affected patient treatment by leading to either pre-prosthetic surgery or a medical referral. The six PRFs included 1 root tip, 1 root fragment, 1 intact root (with a fractured-off crown), 1 impacted tooth, osteophytes on the spine of one patient, and 1 suspected CCAA.
Table 11: Total expert positive radiographic findings (PRFs) for each student group and the effect on treatment as determined by the students

<table>
<thead>
<tr>
<th>PRF Category</th>
<th>ICC PRFs</th>
<th>IPROS PRFs</th>
<th>TOTAL PRFs (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiopacity</td>
<td>41</td>
<td>51</td>
<td>92</td>
</tr>
<tr>
<td>Radiolucency</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Mixed Lesion</td>
<td>7</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>Extragnathic</td>
<td>23</td>
<td>33</td>
<td>56</td>
</tr>
<tr>
<td><strong>TOTAL PRFs</strong> i</td>
<td>72</td>
<td>93</td>
<td>165</td>
</tr>
</tbody>
</table>

- **Unit of measure** is the positive radiographic finding (PRF)
- these were the PRFs **identified by the experts** for each student group
i) \( p = 0.18 \) (Bonferroni corrected t-test); **no significant** statistical difference in total PRFs between ICC (72) and IPROS (93) patients as identified by the experts (i.e. student population groups are similar)

* “Treatment Affected” percentages divided by 169 (total panoramic radiographs)

The 92 RO lesions identified by the experts consisted of 33 root fragments, 25 were suggestive of dense bone island (DBI) or possible condensing osteitis (CO) depending on how recently a tooth may or may not have been extracted, 15 foreign bodies (14 amalgam tattoos, 1 surgical dressing), 12 sinus mucositis, 3 root sealer/cement excess, 1 bone sequestrum, 1 osteoma/exostosis, 1 antral mucus retention cyst and 1 localized sclerosing osteomyelitis. The RO lesions identified here do not include SHL calcifications or EN lesions.

The four RL lesions were identified as 1 each: nasopalatine cyst, lingual bone defect, residual cyst, and dehiscence on the coronoid process of the TMJ.

The 13 ML were identified as 7 impacted teeth, 4 retained roots, 1 osseous dysplasia, and 1 unknown mixed lesion on the condyle [unknown differential diagnosis (DDx)].

The 56 EN lesions were interpreted as 27 CCAAs, 9 tritecious cartilage, 8 calcified lymph nodes (LN) of the neck, 5 tonsiloliths, 3 osteophytes on cervical vertebrae, 3 submandibular gland calculi, and 1 parotid gland calcification. Of these EN lesions, 44 could have potentially had a differential diagnosis of CCAA by an untrained clinician (27 CCAAs, 9 tritecious cartilage, and 8 calcified LN of the neck). All 56 EN lesions were radiopaque, but are
not included under RO lesions, which were restricted to those in the denture-bearing areas. With 27 CCAAs identified by experts (subtracting the 1 already referred by students), that is an additional 26 patients who should have had either a referral or a follow-up with a physician. Including the localized sclerosing osteomyelitis and the one unknown mixed lesion on the condyle the effect on treatment could hypothetically increase from 3.6% as identified by students to 20.1% (34/169) as identified by students and experts (6 + 28).

As compared to the experts, both student groups (ICC and IPROS) had false positive (FP) and false negative (FN) findings or errors in their radiographic interpretations, which were recorded as radiographic interpretation errors (RIEs) (Tables 12 and 13). There was no significant statistical difference (p= 0.0586) in the total number of RIEs (FP and FN) between ICC and IPROS students, although there was a tendency for IPROS students to make more FP and FN findings for each radiographic category examined (Table 13).

Table 12: Number of radiographic interpretation errors (RIEs) made by students

<table>
<thead>
<tr>
<th>Number of RIEs per Pan</th>
<th>ICC RIEs</th>
<th>IPROS RIEs</th>
<th>TOTAL RIEs (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>44</td>
<td>33</td>
<td>87/169 (51%)</td>
</tr>
<tr>
<td>1</td>
<td>34</td>
<td>23</td>
<td>57/169 (34%)</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>10</td>
<td>17/169 (10%)</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>6</td>
<td>6/169 (4%)</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>2</td>
<td>2/169 (1%)</td>
</tr>
<tr>
<td>TOTAL Pans with RIEs (False Positives + False Negatives)</td>
<td>48</td>
<td>69</td>
<td>---</td>
</tr>
</tbody>
</table>

i) p = 0.0586 (2 tailed t-test); no significant statistical difference in total # of RIEs (FP & FN) between ICC (48) and IPROS (69)

Pan = panoramic radiograph
Table 13: False positive (FP) and false negative (FN) radiographic interpretation errors (RIEs) made in each radiographic category by students

<table>
<thead>
<tr>
<th>Category</th>
<th>ICC FP</th>
<th>ICC FN</th>
<th>Total ICC</th>
<th>IPROS FP</th>
<th>IPROS FN</th>
<th>Total IPROS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiopacity</td>
<td>3</td>
<td>21</td>
<td>24</td>
<td>8</td>
<td>21</td>
<td>29</td>
</tr>
<tr>
<td>Radiolucency</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>9</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Mixed Lesion</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Extragnathic</td>
<td>2</td>
<td>17</td>
<td>19</td>
<td>1</td>
<td>26</td>
<td>27</td>
</tr>
<tr>
<td>TOTAL</td>
<td>9</td>
<td>39</td>
<td>48</td>
<td>18</td>
<td>51</td>
<td>69</td>
</tr>
</tbody>
</table>

3.3 Positional Errors

Of the 169 screening panoramic radiographs reviewed by the experts, 155 (92%) panoramic radiographs had at least one positional error detected (Table 14), while only 14 (8%) of the panoramic radiographs were error free. Nonetheless, 161 (95%) of the screening panoramic radiographs were considered diagnostically acceptable based on the study definition and only eight (5%) were considered unacceptable.

Table 14: Number of panoramic radiographs with positional errors detected

<table>
<thead>
<tr>
<th>Positional Errors</th>
<th>ICC</th>
<th>IPROS</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No errors</td>
<td>4</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>1 error</td>
<td>30</td>
<td>25</td>
<td>55</td>
</tr>
<tr>
<td>More than 1 error</td>
<td>51</td>
<td>49</td>
<td>100</td>
</tr>
</tbody>
</table>

* as reported by the experts

There were 301 total positional errors detected by the experts, subdivided into eight categories (right and left head shift, right and left head rotation, chin up, chin down, improper tongue position, and “other”). Table 15 shows the positional errors detected by the students (ICC and IPROS) compared to the experts. The single most common positional error (27%) detected in this study was improper tongue position (Table 15). Using the Bonferroni corrected t-test, all the groups in Table 15 showed a statistically significant difference between them in total positional errors detected, except the “Expert ICC” (164) versus “Expert IPROS” (137),
which was p=0.09. Both student groups detected significantly fewer positional errors relative to the experts, with ICC students detecting 13 positional errors compared to 164 by experts (p =0.004), and IPROS students detecting 72 positional errors compared to 137 by experts (p = 0.027). There was also a statistical difference found in positional errors detected between the two student groups (p =0.002), with IPROS students (72 positional errors) detecting significantly more errors than ICC (13 positional errors).

Table 15: Comparison of total positional errors detected by students versus the experts and total positional errors for each category

<table>
<thead>
<tr>
<th>Positional Error Category</th>
<th>ICC Student</th>
<th>Expert ICC</th>
<th>IPROS Student</th>
<th>Expert IPROS</th>
<th>Expert TOTAL</th>
<th>% of total errors**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Head Shift</td>
<td>0</td>
<td>2</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>4%</td>
</tr>
<tr>
<td>Left Head Shift</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Right Head Rotation</td>
<td>0</td>
<td>5</td>
<td>8</td>
<td>8</td>
<td>13</td>
<td>13%</td>
</tr>
<tr>
<td>Left Head Rotation</td>
<td>1</td>
<td>14</td>
<td>6</td>
<td>12</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Chin Down</td>
<td>2</td>
<td>11</td>
<td>6</td>
<td>10</td>
<td>21</td>
<td>21%</td>
</tr>
<tr>
<td>Chin Up</td>
<td>2</td>
<td>26</td>
<td>7</td>
<td>16</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Inappropriate Tongue Position</td>
<td>1</td>
<td>43</td>
<td>13</td>
<td>38</td>
<td>81</td>
<td>27%</td>
</tr>
<tr>
<td>Other*</td>
<td>7</td>
<td>60</td>
<td>24</td>
<td>46</td>
<td>106</td>
<td>35%</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td>13</td>
<td>164a</td>
<td>72</td>
<td>137a</td>
<td>301</td>
<td>100%</td>
</tr>
</tbody>
</table>

*aOther = head tilt, artifact, anterior-posterior incorrect positioning, movement, slumped, superimposition of hyoid; **% based on total errors detected by the expert -unit of measure is the positional error detected (not panoramic radiograph)
a) only “TOTALS” that are not statistically different (using Bonferroni corrected paired t-test)
-p = 0.09 (Bonferroni corrected t-test); no significant statistical difference in total positional errors detected for ICC (164) and IPROS (137) patients as identified by the experts (i.e. student population groups are similar)
-p = 0.004 (Bonferroni corrected t-test); significant statistical difference in total positional errors detected between ICC student (13) and the expert (164)
-p = 0.027 (Bonferroni corrected t-test); significant statistical difference in total positional errors detected between IPROS student (72) and the expert (137)
-p = 0.002 (Bonferroni corrected t-test); significant statistical difference in total positional errors detected between ICC student (13) and the IPROS student (72)

Table 16 shows the number of panoramic radiographs with positional errors detected by each student group compared to the experts. While students in IPROS detected significantly more positional errors than did ICC students, the actual number of errors as judged by experts was not different between the two patient pools.
Table 16: Comparison of positional errors detected between students and experts.

<table>
<thead>
<tr>
<th></th>
<th>ICC (n = 85)</th>
<th>IPROS (n = 84)</th>
<th>TOTAL Expert</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Student</td>
<td>Expert</td>
<td>Student</td>
</tr>
<tr>
<td># of pans with</td>
<td>10</td>
<td>81a</td>
<td>49</td>
</tr>
<tr>
<td>positional errors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>detected</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Unit of measure is the panoramic radiograph

a) only groups that are not statistically different (using 2-tailed student t-test)

- Using 2-tailed t-test:
  - ICC (81) expert vs. IPROS expert (74) p = 0.09; not statistically different
  - ICC student (10) vs. expert ICC (81) p = 3.2x10^{-5}; statistically different
  - IPROS student (49) vs. expert IPROS (74) p = 9.3x10^{-6}; statistically different
  - ICC student (10) vs. IPROS student (49) p = 2.9x10^{-11}; statistically different

Table 17 compares the true positives (TPs), true negatives (TNs), FPs and FNs across all positional error categories made by each student group compared to the experts.

Table 17: True positives, true negatives, false positives, and false negatives of positional errors detected across all categories

<table>
<thead>
<tr>
<th></th>
<th>ICC Student</th>
<th>Expert ICC</th>
<th>IPROS Student</th>
<th>IPROS Expert</th>
</tr>
</thead>
<tbody>
<tr>
<td>True Positives (TPs)</td>
<td>11</td>
<td>164</td>
<td>56</td>
<td>137</td>
</tr>
<tr>
<td>True Negatives (TNs)</td>
<td>259</td>
<td>261</td>
<td>267</td>
<td>283</td>
</tr>
<tr>
<td>False Positives (FPs)</td>
<td>2</td>
<td>0</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>False Negatives (FNs)</td>
<td>153</td>
<td>0</td>
<td>81</td>
<td>0</td>
</tr>
</tbody>
</table>

This is tabulated from all 8 categories of positional errors for each panoramic radiograph reviewed

FP + FN = “mistakes” or positional error misidentifications (PEMs)

Note: ICC students had 155 PEMs and IPROS students had 97 PEMs

Note: 164 + 137 = 301 total positional errors detected by experts

Table 18 reports the positional error misidentification (PEMs), also known as the FPs and FNs, made by each student. Using a 2-tailed t-test, a statistically significant difference \(p = 2.5 \times 10^{-5}\) was found between the total number of PEMs made between ICC (155 errors) and IPROS (97 errors). The majority of students (64%) made one or two PEMs per panoramic radiograph (Table 18).
Table 18: Positional error misidentifications (PEM) made by ICC and IPROS students

<table>
<thead>
<tr>
<th>Number of PEMs per Pan</th>
<th>ICC (n=85)</th>
<th>IPROS (n=84)</th>
<th>Pans with PEMs (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6</td>
<td>26</td>
<td>32/169 (19%)</td>
</tr>
<tr>
<td>1</td>
<td>27</td>
<td>29</td>
<td>56/169 (33%)</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>21</td>
<td>53/169 (31%)</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>6</td>
<td>22/169 (13%)</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>2</td>
<td>6/169 (4%)</td>
</tr>
<tr>
<td>TOTAL Pans</td>
<td>85</td>
<td>84</td>
<td>169/169 (100%)</td>
</tr>
<tr>
<td>TOTAL PEM (FP &amp; FN)</td>
<td>155*</td>
<td>97**</td>
<td>---</td>
</tr>
</tbody>
</table>

* 155 PEMs for ICC = (27x1) + (32x2) + (16x3) + (4x4)
** 97 PEMs for IPROS = (29x1) + (21x2) + (6x3) + (2x4)

3.4 Inter-Rater Reliability - Experts

Overall, 43% (73/169) of the screening panoramic radiographs were reviewed by the OMFR throughout the investigation. Twenty-five were reviewed initially, 20 were randomly selected for the blinded inter-rater reliability comparison (including five already accounted for in the pilot project), and 33 others required subject matter expert consultation due to uncertainty from the primary investigator.

Based on the five categories used to evaluate each panoramic radiograph for the observed proportion of agreement, the two experts, Dr. Kratz and Dr. MacDonald, matched 84/100 times for the 20 different radiographs, with a 95% CI of (76%, 92%), such that the probable true value of agreement is between 76% and 92%.
### 3.5 Summary of Key Results

Table 19: Summary of Key Results

<table>
<thead>
<tr>
<th>Result</th>
<th>ICC (n=85)</th>
<th>IPROS (n=84)</th>
<th>TOTAL</th>
<th>Statistical Test Utilized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiographic Interpretations Completed</td>
<td>65 (76.5%)</td>
<td>81 (96.4%)</td>
<td>146</td>
<td>t-test; ( p = 1.4 \times 10^{-4} )</td>
</tr>
<tr>
<td>PRFs Identified by Experts</td>
<td>72</td>
<td>93</td>
<td>165</td>
<td>Bonferroni; ( p = 0.18 )</td>
</tr>
<tr>
<td>Avg. PRF per edentulous patient</td>
<td>0.85</td>
<td>1.1</td>
<td>0.98</td>
<td>CI; (0.81, 1.42/patient)</td>
</tr>
<tr>
<td>PRFs Affect on Treatment</td>
<td>3</td>
<td>3</td>
<td>6 (3.6%)</td>
<td>CI; (0.8%, 6.3%)</td>
</tr>
<tr>
<td>RIEs by Students</td>
<td>48</td>
<td>69</td>
<td>117</td>
<td>t-test; ( p = 0.0586 )</td>
</tr>
<tr>
<td>Positional Errors Detected by Experts</td>
<td>164</td>
<td>137</td>
<td>301</td>
<td>Bonferroni; ( p = 0.09 )</td>
</tr>
<tr>
<td>Positional Errors Detected by Students</td>
<td>13</td>
<td>72</td>
<td>85</td>
<td>Bonferroni; ( p = 0.002 )</td>
</tr>
<tr>
<td>PEMs by Students</td>
<td>155</td>
<td>97</td>
<td>252</td>
<td>t-test; ( p = 2.5 \times 10^{-5} )</td>
</tr>
<tr>
<td>Inter-Rater Reliability</td>
<td>N/A</td>
<td>84/100</td>
<td>CI; (76%, 92%)</td>
<td></td>
</tr>
</tbody>
</table>

**BOLD** represents statistical significant difference
Avg. = average; ICC =72/85; IPROS = 93/84
pan = panoramic radiograph
CI = Confidence Interval
Chapter 4: Discussion

4.1 Positive Radiographic Findings (PRFs)

4.1.1 Yield of Positive Radiographic Findings

The yield of PRFs has been reported to be between 16-61% for edentulous patients and as high as 68% (140/205) in the study by Bohay et al. The current study had similar result, with 60% (101/169) of the digital panoramic radiographs having PRFs. This suggests that even with the ability to enhance digital panoramic radiographs, more PRFs are not necessarily identified in the edentulous patient. However, given the fact that 60% of the images had PRFs and this did not include such things as maxillary sinus pneumatization and mental foramina at or near the crest of ridge, which are frequently identified and counted in other panoramic surveys, one could surmise that digital panoramic radiographs did enhance the ability of the practitioners to identify PRFs.

Based on the parameters and definitions presented, certain PRFs identified in other studies such as stylohyoid ligament (SHL) calcification, pneumatization of the maxillary sinus, and mental foramen on or near the crest of the alveolar ridge were not reported in our data as PRFs. It was believed these would just inflate the high yield of PRFs without an effect on treatment planning for CRDP.

The data collected on SHL calcifications/elongations were not included as they are no longer considered a pathological condition, or at best their status is controversial. SHL calcification was first reported by Gossman and Taaristano in 1977. Based on the four developmental regions of the stylohyoid complex, 12 common patterns of calcification of the SHL have been reported. The calcification or elongation of SHL was thought to be related to
Eagles Syndrome, which, if the elongated SHL extends below the level of the middle of the mandibular canal, could lead to referred facial pain, foreign body sensation in the throat, and pain on swallowing and turning of the head. A calcified or elongated SHL could potentially be mistaken for a CCAA on a panoramic radiograph depending on the pattern of calcification, but otherwise it has no effect on the fabrication of a CRDP and was therefore not included as a PRF.

Similarly, maxillary sinus pneumatization is not reported in this study as it occurs frequently in the edentulous portion of the posterior maxilla. Similar to SHL calcification, it would inflate the high yield of PRFs without consequence to treatment outcome for conventional CRDP.

Finally, mental foramina at or near the crest of the residual ridge were not reported as PRFs. Similar to pneumatization, this is an anatomical change frequently encountered after tooth loss and resulting residual ridge resorption over time and would inflate the yield of PRFs. It is not uncommon to see the mental foramen on the ridge crest in a third or more of the patients being treated for CRDP. Moreover, despite the fact that they have been reported in other screening panoramic radiograph studies, it was decided they could be identified clinically via palpation, whereas other PRFs may not be so readily detected (e.g. impacted tooth, root fragment, pneumatization of the sinus, CCAA). Although, there is a chance that a superficial mental foramen could affect treatment, in no other studies evaluated did the mental foramen on the crest of the ridge result in the need to perform pre-prosthetic surgery to increase the opening of the mental foramen downward to the inferior border of the mandible. If the mental foramen is near the crest of the ridge, a selective pressure impression technique could be used or the
CRDP could be relieved in the region\textsuperscript{73}. Although it may be argued that this is an alteration in treatment management, and could be seen as a limitation of this study, such denture modifications were deemed to be within the normal process of conventional complete denture fabrication in Prosthodontics, given the average age of the population being treated for edentulism.

Given the high yield of PRFs, only two patients (localized osteomyelitis and an unknown ML of the condyle) were identified as requiring further follow-up and investigation. Only one could be contacted, and he had no symptoms or complaints and was not interested in a no-charge follow-up at the UBC Oral Health Centre. Other than these two patients, no other serious pathoses, such as infection, malignancies or tumours were discovered from the panoramic survey. Moreover, only six patients out of the 169 (3.6\%) who had a screening panoramic radiograph had a PRF that affected their treatment or management prior to CRDP fabrication.

4.1.2 Effect on Treatment of Positive Radiographic Findings

In the study by Keur et al, they found 34\%\textsuperscript{14, 72} of PRFs had an effect on treatment, which was much higher than previously reported ranges between 0-8.3\% of PRFs affecting treatment (Table 7)\textsuperscript{15, 18, 59, 62, 64, 66-71}. This appears to be because in Keur and colleagues’ 1987 study\textsuperscript{72}, all root tips/fragments and unerupted teeth were referred to an OMFS regardless of symptoms or pathology. These referrals were considered an effect on treatment similar to the current study definitions. However, the authors did not comment on how many patients referred to the OMFS for retained roots or teeth actually received surgical intervention. Similarly, if referrals for the 44 EN lesions with a possible differential diagnosis of CCAA by an untrained eye were referred, this would have increased the PRFs effect on treatment from 3.6\% (6/169) to 29.0\% (49/169), approaching the 34\% reported by Keur et al\textsuperscript{14, 72}. A referral for a potential CCAA is indicated
either to an Oral and Maxillofacial Radiologist for definitive diagnosis with an elevated-chin posterior-anterior cephalometric radiograph or ultrasonography if required, or to a physician depending on the patient’s medical history for prevention of a possible stroke (discussed later)\textsuperscript{100, 107, 110, 111}.

False positives of CCAA can occur and if appropriate measures are not taken to properly identify the PRF it can lead to costly and inappropriate diagnostic tests. It has been shown that a panoramic radiograph only has a sensitivity of 22.2\% for detecting CCAAs and a specificity of 90.0\%\textsuperscript{112}. CCAAs generally present on panoramic radiographs as irregular curvilinear parallel ROs about 2cm below the angle of the mandible. They are usually below the third or fourth cervical vertebrae lateral or inferior to the hyoid bone. The prevalence of CCAAs ranges between 2 – 4.5\% on panoramic radiographs of asymptomatic adults over the age of 50 years without systemic medical risk factors such as cardiomyopathy, type 2-diabetes, renal disease and obstructive sleep apnea. To an inexperienced reviewer numerous radiopacities in the area of the lateral neck could be mistaken for a CCAA: salivary calculi, calcified LNs, tonsilloliths, triticeous cartilage, calcified stylohyoid ligament and medial artery arteriosclerosis (MAA) or Monckeberg’s medial calcific sclerosis. If a differential diagnosis of CCAA is identified on a panoramic image and one is in doubt, the first step should be to consult an OMFR specialist. Furthermore, one could prescribe a modified (chin-elevated) posterior-anterior cephalometric radiograph with soft-tissue exposure settings to come to a definitive diagnosis\textsuperscript{107}.

Once a definitive diagnosis of CCAA is confirmed, this does not imply an automatic referral to a physician. There are several factors to consider: the patients neurological symptoms, whether they are already undergoing treatment for cardiovascular disease, whether hypertension is controlled and below 140mmHg systolic and 90 mmHg diastolic, their age, other co-
morbidities and social habits such as smoking and alcohol consumption that can increase the risk of cardiovascular disease or cerebrovascular disease. The decision to refer to a physician for management and follow-up will depend on the interplay of these important medical and social findings. Generally speaking, patients with uncontrolled or a sustained elevated hypertension should be referred for immediate medical consultation by written referral in the presence or absence of CCAA. Additionally, it is recommended that for patients with a definitive diagnosis of a CCAA on panoramic radiographs with controlled hypertension still be followed-up with an informal telephone consultation with the physician to discuss and inform the primary caregiver about the radiographic finding. Nothing may change in the medical therapy, but this follow-up could lead to minor alterations in the patient’s treatment that may include an increase or switch in antihypertensive medications, smoking cessation, antihyperlipidemia medication, and aspirin antithrombolytic therapy if not already part of the treatment regime\(^{107}\).

Despite the potentially serious medical concerns associated with CCAAs, the current ADA guidelines specifically state that panoramic radiographs are not indicated for the detection of CCAAs and are not a justification for screening radiology\(^2\). However, if a screening panoramic radiograph is taken and a thorough satisfaction of search is carried out that identifies EN PRFs that are potential CCAAs, as discussed above, this will either lead to further exposure of the patient to ionizing radiation to comprehensively investigate the differential diagnosis of a CCAA, or a heavy referral burden to an OMFR to definitively diagnose the EN finding prior to a possible medical referral\(^{107}\).

Four out of six (67%) PRFs that affected treatment included root tips/fragments and an impacted tooth, while the other 2 referrals were for osteophytes on the spine (risk of arthritis) and a suspected CCAA (risk of stroke) according to the Electronic Health Record (EHR) (Table
Upon reassessment of the EHR, it was noted that two of the root tips/fragments could be detected visually, and a third had presented clinically with a draining fistula. This would reduce the overall percentage of PRFs effect on treatment discovered incidentally from the screening panoramic radiographs to 1.8% from 3.6%, as it would leave only three occult findings that could not have been identified via an intra-oral clinical examination. Given the high number of retained teeth, roots, or root fragments (45) detected (Table 10) and the fact that there was only one FN for mixed lesions for both student groups (Table 13), (which includes unerupted/impacted teeth and retained roots, but not root fragments), this suggests that students are well informed with respect to the clinical situations in which retained roots and teeth can be left in-situ with minimal consequence to complete denture fabrication.

4.1.3 Radiographic Interpretation Errors (RIEs)

Overall, there was no statistically significant difference (p= 0.0586) in radiographic interpretation errors (RIEs) between the student groups (ICC had 48 RIEs and IPROS 69 RIEs) (Table 12). However, there was a tendency for the IPROS students to make more RIEs for each radiographic category examined (Table 13). This could be partially explained because IPROS students interpreted significantly more (p = 0.00014) radiographs than ICC (Table 9). In addition, the slightly smaller number of RIEs made by ICC students could be attributed to their gain in clinical experience as they progress through dental school and near graduation.

Finally, with respect to RIEs, both student cohorts looked at the digital images on the clinic floor using conventional computer monitors in a bright environment. This could increase the likelihood of FNs, compared to the experts, who evaluated each radiograph on a special MGDG high brightness monitor under reduced ambient lighting. EN radiographic findings typically had the most FNs of all four categories at 43 (Table 13). Even with the ability to
enhance digital radiographs, many PRFs were missed in the clinic. The high level of missed EN findings suggest that students should be reminded not to just examine the dento-alveolar complex, but also to complete a thorough satisfaction of search (SOS) when completing a radiographic interpretation.

4.2 Positional Errors

4.2.1 Positional Errors Detected: Comparison to the Literature

Not only did the high yield of PRFs not yield a high number of clinically significant findings, with only 3.6% of the PRFs affecting treatment, but a high number of FP and FN findings were made by students on the screening panoramic radiographs with positional errors that could negatively influence the ability to diagnose radiographic lesions\textsuperscript{18}. The literature has shown that there is increased difficulty in properly positioning edentulous patients, which affects the ability to properly diagnose occult pathology on a panoramic radiograph\textsuperscript{20, 21, 32-35, 37, 38} (Figures 9a and 9b). In the current study, 92% (155) of the panoramic radiographs had at least one positional error, which is similar to the average of 89.2% (801.3/9) in the nine studies reviewed in Table 2. The high incidence of positional errors in both the current and reviewed studies supports the difficulty in positioning edentulous patients for panoramic radiographs and the importance of properly trained dental staff to make such images.

Notwithstanding the high level of positional errors detected in this study by the experts, 95% of the images were deemed “diagnostically acceptable,” allowing adequate visibility of the maxilla and mandible prior to CRDP fabrication. The 5% of images (n=8) deemed diagnostically unacceptable after-the-fact by the experts, but missed in real-time by the students and their instructors, could have contributed to radiographic interpretation errors on the part of the students as they proceeded with a poor quality image.
The NRPB guidelines for international quality standards for panoramic radiographs have been previously challenged to remove the category of “excellent,” due to the seemingly unfeasible task of creating an error free panoramic image, especially in edentulous patients\textsuperscript{20, 35}. Others have argued for new goals, which aim to reduce “unacceptable” panoramic images to less than 10% and achieve a standard of 90+% diagnostically “acceptable”\textsuperscript{20, 21}. The results of our study would meet these new, achievable standards; although such a change may down play the clinical relevance of detecting positional errors, which do increase the chances of FN or missed radiographic findings\textsuperscript{18, 113}. 
Figure 9A and 9B: Positional errors on panoramic radiographs can affect diagnosis.
Images from the following website [http://www.dentalxrays.info/blog/correct-panoramic-positioning-key](http://www.dentalxrays.info/blog/correct-panoramic-positioning-key)\textsuperscript{113}. Top image (A) and bottom image (B) are from the same patient. Fig 9A (top image): the patient is too far forward (thus minimized Md anterior teeth) and chin-up (“frown”). Fig 9B (bottom image): the patient is positioned correctly, with Md in focal trough and chin (or Frankfurt horizontal plane) more parallel to the floor, however this was still difficult due to kyphosis. Although this patient is dentate, it shows clearly how incorrect position can lead to FN, as is apparent with the unerupted cuspid with a possible dentigerous cyst surrounding the crown.

Studies examining positional errors show a variation in the most common patient positioning errors identified, listing failure to position the tongue against the palate\textsuperscript{20, 21, 32, 40}.
head rotations to the left/right\textsuperscript{34,37} or chin positioning\textsuperscript{33} as the most common errors detected. 

Table 3 compares five studies that described similar categories of positional errors to the current study. Once again, the data for the positional errors identified by the experts in the current study are very similar to the reported literature averages, with malposition of the tongue being the single most prevalent positional error identified at 26.9\% compared to the average of 24.9\% in the five listed studies. This common mistake can be overcome by simply reminding the patient to swallow, and press the tip of their tongue to the roof of the mouth for the duration of the radiographic exposure. Having a well-trained staff member to consistently remind patients of this, plus several other important positional tips, could substantially reduce positional errors identified on panoramic radiographs of edentulous patients.

4.2.2 Positional Error Misidentifications (PEMs)

When it came to evaluating the positional errors identified by each student cohort, IPROS and ICC, there was a statistically significant difference (p = 0.002) (Table 15), as well as between each student group and the experts. These significant differences occurred at both the level of the panoramic radiograph and the overall total number of positional errors detected (Tables 15, 16, 17 and 18). Looking at Table 16, 3\textsuperscript{rd} and 4\textsuperscript{th} year dental students in ICC reported significantly fewer (p=2.9x10\textsuperscript{-11}) panoramic radiographs with positional errors (10) compared to the IPROS students (49). This translated to more FNs or missed positional errors detected in ICC (153) compared to IPROS (81) (Table 17). Not surprisingly, the ICC cohort therefore had less FPs (2 vs. 16) as well (Table 17). These differences between the ICC and IPROS can be attributed to a few factors. First, the ICC cohort did not interpret as many panoramic radiographs to begin with (Table 9). If the radiographs are not interpreted, any PRF
or positional error present will be missed and result in a FN or positional error misidentification (PEM). Conversely, this would lead to a tendency to minimize FPs as well.

Other factors contributing to a significant difference in PEMs between the student groups are the amount of time devoted to examining the radiographs and possibly the lighting conditions under which the radiographic images are generally observed. Both student groups had a statistically significant difference from the experts at detecting positional errors (Table 15 & 16). Similar to the RIEs, part of the difference could be accounted for by the poorer lighting conditions under which the students review the radiographs compared to the experts. However, since both student groups evaluated the panoramic radiographs under the same bright clinical lighting conditions, that would only explain the difference between the students and the experts. One factor could be that an entire clinical session is devoted in IPROS to interpretation of the assigned patient’s panoramic radiograph, and faculty and staff experts are available for this session in addition to the “regular” clinic instructors. In contrast, ICC students devote less time during their clinic sessions to analyzing their patient’s radiographic images and subject matter experts may not have been available. It is possible that in an ICC student’s busy schedule, noting positional errors is viewed as clinically less significant than identifying PRFs, which could have an effect on patient treatment. The current study shows, along with the reviewed literature, that on average about 90% (Table 2) of edentulous panoramic images have positional errors. Yet the panoramic images are still “diagnostically acceptable” in the majority of cases (95% according to this study). If the students are aware of this, either intuitively or from their minimal experience, it implies that taking the time to record or even identify the positional errors may be viewed by students as clinically insignificant to the treatment of the patient in most cases, and thus is ignored or quickly bypassed in Romexis™, the primary EHR used at the UBC.
Oral Health Centre. Given how Romexis is set-up with drop box menus, and the low association seen between common positional errors and overall diagnostic quality of the panoramic images, the students presumably select “diagnostic” under the “image evaluation” tab and then “adequate,” rather than taking their limited time in the busy clinic to identify what they believe to be “inconsequential” positional errors. This seems to be corroborated by the fact that the ICC students recorded 88% (75/85) of the panoramic radiographs as “adequate,” or free of positional errors, compared to only 4/85 being detected as error free by the experts for the same cohort (Table 16). This would then allow students to move on to the “radiographic interpretation” tab in Romexis™ with more time to look for dental anomalies or PRFs that may be viewed by the students as having more clinical significance to treating the edentulous patient for CRDP.

The other option under “image evaluation” in Romexis™ is “non-diagnostic,” which is seldom the case despite the numerous positional errors. This explanation of the students’ possible rationale is supported by the evidence seen in this current study with 155/169 panoramic images showing 1 or more positional errors, yet only 8 images being classified as “non-diagnostic” for the evaluation of the maxilla and mandible prior to CRDP fabrication.

Consequently, ICC students may not report positional errors, leading to the higher number of missed positional errors or FNs and the limited number of FPs (i.e. it is difficult to incorrectly identify a positional error or “create” a positional error that does not exist, if you do not analyze the image). In contrast, IPROS students have an entire class session devoted to interpreting a panoramic image, for both “image evaluation” (positional errors) and “radiographic interpretation” (radiographic findings).

Finally, it could also be that dental schools generally do not spend as much time teaching about positional errors in the undergraduate oral radiology curriculum. More class time is usually
devoted to developing differential diagnoses for ROs, RLs and MLs, once again underscoring the relative importance of identifying PRFs over positional errors. Therefore, once ICC students have a little more liberty and are not under the careful scrutiny that IPROS students receive during their “panoramic interpretation” session, they may be more likely to focus on what they perceive to be more clinically relevant based on their educational experience, quickly filling out the image evaluation (positional errors) so they can focus on the radiographic interpretation (PRFs). The combinations of all of these factors may well account for the significantly fewer (p=2.5x10^{-5}) positional error misidentifications (PEMs) or FP and FNs seen in IPROS (97) compared to ICC (155) (Table 18).

4.3 Inter-Rater Reliability

The primary reviewer was not an OMFR specialist, but a general dentist in a graduate Prosthodontics clinical specialty program, so the observed proportion of agreement (a.k.a percent agreement) statistic was used\textsuperscript{103}. This was implemented to improve the internal validity of the study and minimize what could be considered a limitation of the study. An “agreement” was any category of the radiographic evaluation where the two experts matched completely and it relates to the consistency between the primary investigator and the OMFR. The five categories used for the observed proportion of agreement on the 20 randomly selected panoramic radiographs included RO, RL, ML, EN and SHL calcification. Dr. Kratz and Dr. MacDonald, matched 84/100 times for the 20 different radiographs that were blindly reviewed. This had a 95% CI of (76%, 92%), which means the probable true value of agreement is between 76% and 92%. When using the Kappa statistic or any measure of agreement, such as the observed proportion of agreement, there is generally no agreed-upon measure of significance. However, guidelines do exist. Similar to the Kappa statistic, based on the arbitrary guidelines of Fleiss's, values over
0.75 are characterized as excellent, 0.40 to 0.75 as fair to good, and below 0.40 as poor\textsuperscript{114}. Thus, in this study the two experts had excellent agreement (b/w 76-92\%),\textsuperscript{114} which strengthens the internal validity of the results.

4.4 Statistical Significance of Results versus Clinical Significance

As discussed in Section 1.4, there are opposing viewpoints on the use of screening radiographs for edentulous patients as a tool to identify occult pathology prior to conventional denture fabrication. A key argument by proponents of screening radiography is the ability to potentially identify an asymptomatic, but highly morbid PRF, which could potentially be treated early and have huge clinical significance to the patient. However rare the positive radiographic finding may be, identifying an aggressive or malignant lesion has a significant clinical impact for the patient and the clinician, despite the low statistical probability of occurrence in asymptomatic patients\textsuperscript{16, 22, 27}. Taking the perspective of clinical significance with the current study, the primary results will be presented again in this context alongside their corresponding statistical significance in Table 20.
Table 20: Statistical versus clinical significance of key results

<table>
<thead>
<tr>
<th>Result</th>
<th>ICC</th>
<th>IPROS</th>
<th>Statistical Difference Detected</th>
<th>Clinical Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age(^{1}) (avg ± SD) yrs</td>
<td>73.8 ± 11.9</td>
<td>67.5 ± 11.8</td>
<td>YES</td>
<td>NO – both groups &gt;65yrs of age</td>
</tr>
<tr>
<td>Radiographic Interpretations Completed(^{ii})</td>
<td>65 (76.5%)</td>
<td>81 (96.4%)</td>
<td>YES</td>
<td>YES – tighter quality control ensures radiographic and diagnostic information is evaluated</td>
</tr>
<tr>
<td>PRFs Identified by Experts(^{iii})</td>
<td>72</td>
<td>93</td>
<td>NO</td>
<td>YES – student cohorts are similar</td>
</tr>
<tr>
<td>Avg. PRF per edentulous patient(^{iv})</td>
<td>0.98</td>
<td>N/A</td>
<td></td>
<td>YES - 1° objective: occult findings expected on screening pans but do not necessitate the exposure of pt to ionizing radiation</td>
</tr>
<tr>
<td>PRFs Affect on Treatment(^{v})</td>
<td>6 (3.6%)</td>
<td>N/A</td>
<td></td>
<td>YES – 1° objective: similar to existing literature PRFs on screening Pans have low chance of affecting Tx prior to CRDP fabrication</td>
</tr>
<tr>
<td>RIEs by Students(^{vi})</td>
<td>48</td>
<td>69</td>
<td>NO</td>
<td>YES – as students gain experience, they improve at interpreting radiographs as seen by decreased RIEs</td>
</tr>
<tr>
<td>Positional Errors Detected by Experts(^{vii})</td>
<td>164</td>
<td>137</td>
<td>NO</td>
<td>YES – student cohorts are similar</td>
</tr>
<tr>
<td>Positional Errors Detected by Students(^{viii})</td>
<td>13</td>
<td>72</td>
<td>YES</td>
<td>YES – If students are more actively supervised, they take the time to record and identify positional errors and are more likely to detect them</td>
</tr>
<tr>
<td>PEMs by Students(^{ix})</td>
<td>155</td>
<td>97</td>
<td>YES</td>
<td>YES – students may view identifying positional errors as less important compared to identifying PRFs and/or they are less educated at detecting them and thus, without close supervision have more PEMs</td>
</tr>
<tr>
<td>Inter-Rater Reliability(^{x})</td>
<td>84/100 matched (84%)</td>
<td>N/A</td>
<td>&gt; 75%, Excellent Agreement between experts</td>
<td></td>
</tr>
</tbody>
</table>

\(^{1}\) \(p = 0.00069\) (2-tailed t-test); **significant** statistical difference in age between ICC and IPROS

\(^{ii}\) \(p = 0.00014\) (2-tailed t-test); **significant** statistical difference in panoramic radiograph interpretations completed between ICC and IPROS

\(^{iii}\) \(p = 0.18\) (Bonferroni corrected t-test); \(n.s\) statistical difference in total PRFs between ICC (72) and IPROS (93) patients as identified by the experts (i.e. student population groups are similar)

\(^{iv}\) The 95% CI was (0.81, 1.42) for PRFs/patient

\(^{v}\) The 95% CI was (0.8%, 6.3%) for percentage of PRFs affecting patient treatment prior to CRDP

\(^{vi}\) \(p = 0.0586\) (2 tailed t-test); \(n.s\) statistical difference in total # of RIEs (FP & FN) between ICC (48) and IPROS (69)

\(^{vii}\) \(p = 0.09\) (Bonferroni corrected t-test); \(n.s\) statistical difference in total positional errors detected for ICC (164) and IPROS (137) patients as identified by the experts (i.e. student population groups are similar)

\(^{viii}\) \(p = 0.002\) (Bonferroni corrected t-test); **significant** statistical difference in total positional errors detected between ICC student (13) and the IPROS student (72)
NOTE: Using Panoramic radiograph as unit of measure (Table 16), there was also a significant difference between ICC student (10) vs. IPROS student (49) at detecting positional errors $p = 2.9 \times 10^{-11}$ (2 tailed t-test) ix) $p = 2.5 \times 10^{-5}$ (2 tailed t-test); significant statistical difference in “TOTAL PEMs” (FP & FN) between ICC (155) and IPROS (97) x) The 95% CI for the observed proportion of agreement (aka percent agreement) was (76%, 92%)
Chapter 5: Conclusion

5.1 Conclusions

The results of the current study clearly demonstrate that, even with the advancement of digital radiography and the ability to improve images post-processing, screening edentulous patients with routine or pre-treatment panoramic radiographs does not provide an overall net benefit to the patient and only in a very low percentage of the patients (3.6%) actually affects their dental management prior to CRDP fabrication. Thus, the primary null hypothesis was accepted.

Only a small percentage (3.6%) of the positive radiographic findings were clinically significant and affected the treatment of edentulous patients prior to conventional complete denture fabrication, supporting the recommendation that selective radiography should be prescribed based on the patient’s signs and symptoms and past medical and dental histories. In fact, of the six PRFs that affected treatment, half were identifiable clinically, which further lessens the net benefit of the screening panoramic image. Additionally, by exposing a patient to a panoramic radiograph the clinician becomes responsible for completing a thorough investigation or satisfaction of search and appropriate follow-up of extragnathic findings that resemble a CCAA. Given that panoramic radiographs only have about 20% chance of detecting a true positive (sensitivity) for CCAAs, the appropriate follow-up can lead to further unnecessary exposure to ionizing radiation to provide a definitive diagnosis with an elevated-chin posterior-anterior cephalometric radiograph. In conclusion, these results do not support the use of routine pre-treatment panoramic radiographs in edentulous patients prior to complete removable dental prosthesis fabrication.
Secondarily, a quality assurance assessment of the panoramic radiographs made for denture patients at the UBC Oral Health Centre was completed by comparing two student groups, in the 2nd year Introduction to Prosthodontics (IPROS) and 3rd/4th year Integrated Clinical Care (ICC) courses. The null hypothesis was rejected in 2 out of 3 outcomes measured for assessing the quality of the panoramic radiographs. There was a significant difference in the number of radiographic interpretations completed and positional errors detected by the students. However, for the third quality assurance aspect, the null hypothesis was accepted as there was no significant difference in radiographic interpretation errors made by the students. In conclusion, students need to be mindful not only of the clinical guidelines in place for radiographic prescription criteria, but also the importance of taking the time to interpret the panoramic images under appropriate viewing conditions and identifying any positional errors. Such errors can impact the diagnostic quality of the image, especially in edentulous patients who are difficult to correctly position, thus increasing the chance of missed radiographic findings. In order to help reduce the positional errors, yearly training of auxiliary staff can be given and/or designated staff could be employed or specially trained for the main purpose of correctly positioning edentulous patients for panoramic radiographs.

5.2 Significance of the Research

The knowledge gained from this retrospective study analyzing the effect of PRFs on the treatment of edentulous patients and evaluating the positional errors detected can be applied in several ways at the UBC Oral Health Centre and other similar institutions. First, institutions treating or educating people who directly impact the health and decisions of patients should follow the evidence-based guidelines currently published. A good medical and dental history, followed by a thorough clinical exam should be competed prior to exposing a patient to ionizing
radiation\textsuperscript{1-7}. Screening panoramic radiographs of edentulous patients have been shown to have minimal effect on treatment as corroborated by this study using digital radiography. It is important to continue to educate students and staff on the proper radiographic guidelines published in North America so they develop evidence-based habits, such as selective radiography to better care for their patients\textsuperscript{2,9-12,17}. Guidelines for panoramic imaging can include the following positive findings during the history and/or clinical examination:

- history of jaw pain or trauma,
- family history of dental anomalies,
- post-operative evaluation of healing,
- presence of implants, previous implant-related pathosis or evaluation of implant placement,
- impacted teeth,
- swelling or mobility of teeth,
- clinically suspected sinus pathosis,
- oral involvement in known or suspected systemic disease,
- pain and/or dysfunction of the temporomandibular joints,
- facial asymmetry,
- unexplained bleeding,
- growth abnormalities,
- unusual spacing or migration of teeth, and
- unexplained absence of teeth\textsuperscript{8}
This list is not all encompassing, and given other imaging modalities such as magnetic resonance imaging (MRI) and cone-beam computed tomography (CBCT), panoramic imaging may not necessarily be the most appropriate choice, but it at least offers an inexpensive, accessible first step to clarifying a differential diagnosis.

With respect to the quality of the panoramic radiographs made at UBC for edentulous patients, there was a high rate of positional errors detected. Similar to other literature in this field, the current study found 92% of the radiographic images had positional errors. This indicates a strong need to have trained staff make panoramic radiographs to minimize the positional errors. In the study by Akarslan et al, the panoramic radiographs on edentulous patients made by trained dental assistants showed nearly 30% fewer errors than the reviewed literature average. These positional errors can also lead to increased FNs with respect to PRFs, providing yet another reason to be more selective with radiographs in the edentulous population. Additional in-service training could minimize positional errors and maximize the diagnostic benefits to the patients.

Additionally, a satisfaction of search (SOS) needs to be completed for all radiographic interpretations to minimize the number of FNs, especially in the extragnathic regions. To aid in the reduction of RIEs, radiographic interpretations should be completed in a dimly lit room when possible. One possible method to ensure a SOS and reduced RIEs would be to have 3rd year students (in their first year as part of the ICC), schedule a sit down or treatment planning session with a trained instructor (in a dim lit room to review all radiographs and discuss treatment planning prior to treatment commencement). This would allow students to review panoramic radiographs in a dark room, not on the clinic floor, with a devoted instructor to help maximize the viewing capabilities and the learning experience. This would be an improvement to the
current situation, where the majority of interpretations completed are done as part of regular clinics in the operatory. Since the outset of this study, the UBC Oral Health Centre has already implemented one additional quality assurance practice with respect to radiographs interpretations. Now, all radiographs must be evaluated and interpreted and then signed by a clinic instructor within 2 weeks of exposure, or the electronic patient chart will be locked out and patient treatment cannot proceed until the evaluation and interpretation have been completed.

5.3 Strengths and Limitations of the Research

This study is the first to review digital panoramic radiographs in edentulous patients and identify the impact that positive radiographic findings had on the treatment of CRDPs. Rather than just describing the frequency and types of PRFs, it considers the clinical significance of the findings via their impact on treatment. The level of observed proportion of agreement between the primary investigator and the OMFR specialist was excellent, bringing a high level of internal validity to the study. In addition to the excellent training provided by Dr. MacDonald, his expertise helped to resolve any concerns regarding positional errors or radiographic interpretations. This was especially important for obtaining a definitive diagnosis with extragnathic findings or other PRFs that could be considered clinically significant depending on the differential diagnosis derived by the primary investigator. As well, all digital radiographs were reviewed in a well-controlled diagnostically suitable environment on the same medical grade monitor in a dimly lit room.

Despite the primary investigator being calibrated initially and throughout the study, the fact that the primary investigator was not an OMFR specialist, but a graduate prosthodontics specialist student could be considered a limitation of this study. Furthermore, being a retrospective study, the research was confined to the data within the EHRs and the paper chart,
limiting the ability to ascertain other aspects of the patients attending UBC Oral Health Center. This could have been useful information to see if an association exists between the sample population and PRFs, which may have increased the external validity of the study. As is, the external validity of the study is limited to the population at the UBC Oral Centre and other similar institutional environments. The retrospective nature of the study also limited the sample size such that, according to Cohen, a medium effect size (d=0.44) could be detected at a power (1 - \( \beta \)) of 80% and an \( \alpha = 0.05 \). This restricted sample size along with the need for Bonferroni corrected t-tests to make multiple comparisons and avoid the problems of concluding statistical significance by chance, further reduce the power of the study.

5.4 Future Research

Although the majority of recent studies published, including the current study evaluating digital panoramic radiographs, support current radiographic guidelines, the prevalence of positive radiographic findings in first time denture wearers and the impact on dental treatment has not been documented. Several studies, including this one, look at a mixed population of new and repeat denture wearers. It would be useful to see if a statistically significant difference exists between new denture wearers and existing denture wearers seeking a replacement prosthesis. However, a study such as that could be difficult to justify ethically, given the use of screening panoramic radiography is not supported by the evidence and radiographs should be prescribed based on clinical signs and symptoms and history. Lastly, in this author’s opinion, no study will be able to truly quantify the importance of statistical significance versus clinical significance of PRFs, a central dilemma to the discordant viewpoints seen in the literature surrounding screening panoramic radiographs. This is especially true for the individual who has a potentially life-saving diagnosis made early from a screening panoramic radiograph when they are otherwise
asymptomatic. For both the patient and the clinician, the clinical significance of such a finding would no doubt outweigh the low statistical chance of identifying such a lesion.
Bibliography


