Dose with CBCT, Optimisation and quality assurance for CBCT
Dosimetry of CBCT
Methods of limiting dose
Quality assurance
Staff protection
Learning outcomes

• An understanding of radiation dose associated with CBCT
• An understanding of the CBCT equipment factors that can be adjusted to change the radiation dose delivered to patients
• A description of a quality assurance programme for CBCT, including the use of the SEDENTEXCT quality control phantom
• An understanding of the principles of staff protection
Radiation dose from CBCT
Ten dental X-rays 'raise cancer risk'

By FIONA MACRAE
Last updated at 5.25 PM on 3rd June 2010

Dental X-rays given to millions of Britons every year may dramatically increase the risk of thyroid cancer, scientists warned last night.

Researchers found that patients who had been X-rayed by their dentist at least ten times were more likely to develop the disease.

They have now warned that X-rays should not be given at check-ups or when registering new patients – despite these practices being common in many dental surgeries.

Published paper suggests some orthodontists may expose young patients to unnecessary radiation

Published on January 29, 2011 at 7:08 AM · No Comments

Some orthodontists may be exposing young patients to unnecessary radiation when they order 3-D X-ray imaging for simple orthodontic cases before considering traditional 2-D imaging, suggests a paper published by University of Michigan faculty.

There is ongoing debate in the orthodontic community over if and when to use cone beam computed tomography (CBCT) for orthodontic diagnosis and treatment planning, said Dr. Sunil Kapila, lead author of the paper and chair of the Department of Orthodontics and Pediatric Dentistry at the U-M School of Dentistry.
How X-rays interact with matter

X-ray photon

IONISATION
How X-rays interact with matter

**Direct effect**

1. DNA
2. Reactive radicals
3. $\text{H}_2\text{O}$

**Indirect effect**

$\text{H}_2\text{O}$
Adverse health effects of radiation exposure

Can be divided into TISSUE EFFECTS and STOCHASTIC EFFECTS
Tissue effects

- Erythema of the skin
- Hair loss
- Reduction in bone marrow cell production
- Cataract formation in eye
- “Radiation sickness”
Stochastic effects

- Cancer development in exposed individuals owing to mutation of somatic cells

- Heritable disease in offspring owing to mutation of reproductive (germ) cells

“chance”

700 cancer cases caused by X-rays

X-rays used in everyday detection of diseases and broken bones are responsible for about 700 cases of cancer a year, according to the most detailed study to date (Sam Lister writes). The research showed that 0.6 per cent of the 124,000 patients found to have cancer each year can attribute the disease to X-ray exposure. Diagnostic X-rays, which are used in conventional radiography and imaging techniques such as CT scans, are the largest man-made source of radiation exposure to the general population. Although such X-rays provide great benefits, it is necessary to use mathematical models to estimate the number of cancers caused in Britain and 14 other industrialised countries. The models were based on the number and type of diagnostic X-rays performed every year, and the doses delivered.
How real is the cancer risk?

International Commission on Radiological Protection¹

100 mSv

“linear no-threshold” model

How real is the cancer risk?

“...provides a prudent basis for the practical purposes of radiological protection, i.e., the management of risks from low-dose radiation exposure”

Probability coefficient for cancer risk is $5.5 \times 10^{-2}$ Sv$^{-1}$

Risk from dental radiography

No safe dose of radiation

Medical diagnostic and therapeutic ionizing radiation and the risk for thyroid cancer: a case–control study

Brain and salivary gland tumors related to prior dental radiography: implications for current practice
Risk of cancer and age

<table>
<thead>
<tr>
<th>Age group (years)</th>
<th>Multiplication factor for risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10</td>
<td>x 3</td>
</tr>
<tr>
<td>10-20</td>
<td>x 2</td>
</tr>
<tr>
<td>20-30</td>
<td>x 1.5</td>
</tr>
<tr>
<td>30-50</td>
<td>x 0.5</td>
</tr>
<tr>
<td>50-80</td>
<td>x 0.3</td>
</tr>
<tr>
<td>80+</td>
<td>negligible risk</td>
</tr>
</tbody>
</table>

Multiplication factor at 30 years = 1

* Derived from International Commission on Radiation Protection Recommendations.16
What do we mean by “dose” of radiation? 

Transfer of energy from radiation to atoms

Energy absorbed per unit mass

joules kg\(^{-1}\)

1 joule kg\(^{-1}\) = 1 gray (Gy)

Absorbed dose

But...different types of radiation have different damaging potential for the same dose
What do we mean by “dose” of radiation?

Absorbed dose x Weighting factor

1 Gy x $W_R = 1$ sievert (Sv)

**Equivalent dose**

<table>
<thead>
<tr>
<th>Weighting factors ($W_R$)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X-rays</td>
<td>1</td>
</tr>
<tr>
<td>Electrons</td>
<td>1</td>
</tr>
<tr>
<td>Protons</td>
<td>2</td>
</tr>
<tr>
<td>Alpha particles</td>
<td>20</td>
</tr>
</tbody>
</table>
What do we mean by “dose” of radiation?

Different tissues have different radiosensitivities

<table>
<thead>
<tr>
<th>Tissue</th>
<th>$\omega_T$</th>
<th>$\sum \omega_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone-marrow (red), Colon, Lung, Stomach, Breast, Remainder Tissues*</td>
<td>0.12</td>
<td>0.72</td>
</tr>
<tr>
<td>Gonads</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>Bladder, Oesophagus, Liver, Thyroid</td>
<td>0.04</td>
<td>0.16</td>
</tr>
<tr>
<td>Bone surface, Brain, Salivary glands, Skin</td>
<td>0.01</td>
<td>0.04</td>
</tr>
</tbody>
</table>

*Remainder Tissues: Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate (♂), Small intestine, Spleen, Thymus, Uterus/cervix (♀).
Effective Dose

Weighted sum of equivalent doses to different organs

Dose to brain tissue $\times$ brain weighting factor
  +
Dose to thyroid $\times$ thyroid weighting factor
  +
Dose to bone marrow $\times$ marrow weighting factor
  +
Dose to salivary gland $\times$ salivary gland weighting factor
  +
 etc, etc......

Sum of these = Effective dose (Sv)
CBCT dose estimation

Different parameters to quantify CBCT dose:

1. Anatomical (organ absorbed dose, effective dose)
2. Technical (mAs, CTDI, DAP)

Effective dose is most relevant & comprehensible dose parameter for patient risk
Effective dose

\[ \sum (\text{Equivalent dose} \times w_T \text{ for each organ}) \]

How is this possible in real people?

<table>
<thead>
<tr>
<th>Tissue</th>
<th>( w_T )</th>
<th>( \sum w_T )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone-marrow (red), Colon, Lung, Stomach, Breast, Remainder Tissues*</td>
<td>0.12</td>
<td>0.72</td>
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<tr>
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</tbody>
</table>

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Measuring dose: dosimetry phantoms
Measuring dose: dosimetry phantoms
Measuring dose: dosimeters

Thermoluminescent dosimeters (TLDs)
Lithium fluoride

Superficial use *in vivo*
SEDENTEXCT studies of effective dose from CBCT


14 CBCT scanners studied (24 protocols)

“Adult” phantoms
## Table 1
Technical parameters of selected CBCT exposure protocols.

<table>
<thead>
<tr>
<th>CBCT</th>
<th>Manufacturer</th>
<th>Protocol(^a)</th>
<th>FOV (cm)</th>
<th>Voltage (kV)</th>
<th>mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D Accuitomo 170</td>
<td>J. Morita, Kyoto, Japan</td>
<td>Maxilla</td>
<td>10 × 5</td>
<td>90</td>
<td>87.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower jaw molar region</td>
<td>4 × 4</td>
<td>90</td>
<td>87.5</td>
</tr>
<tr>
<td>Galileos Comfort</td>
<td>Sirona Dental Systems, Bensheim, Germany</td>
<td>Maxillofacial</td>
<td>15 × 15</td>
<td>85</td>
<td>28</td>
</tr>
<tr>
<td>i-CAT Next Generation</td>
<td>Imaging Sciences International, Hatfield, PA, USA</td>
<td>Maxillofacial</td>
<td>16 × 13</td>
<td>120</td>
<td>18.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mandible</td>
<td>16 × 6</td>
<td>120</td>
<td>18.5</td>
</tr>
<tr>
<td>Ilumina Elite</td>
<td>Imtec (3M), Ardmore, OK, USA</td>
<td>Maxillofacial</td>
<td>21 × 14</td>
<td>120</td>
<td>76</td>
</tr>
<tr>
<td>Kodak 9000 3D</td>
<td>Kodak Dental Systems, Carestream Health, Rochester, NY, USA</td>
<td>Upper jaw front region</td>
<td>5 × 3.7</td>
<td>70</td>
<td>107</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower jaw molar region</td>
<td>5 × 3.7</td>
<td>70</td>
<td>107</td>
</tr>
<tr>
<td>Kodak 9500</td>
<td>Kodak Dental Systems, Carestream Health, Rochester, NY, USA</td>
<td>Maxillofacial</td>
<td>20 × 18</td>
<td>90</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dentoalveolar</td>
<td>15 × 8</td>
<td>90</td>
<td>108</td>
</tr>
<tr>
<td>NewTom VG</td>
<td>Quantitative Radiology, Verona, Italy</td>
<td>Maxillofacial</td>
<td>15 × 10</td>
<td>110</td>
<td>10.4</td>
</tr>
<tr>
<td>NewTom VGi</td>
<td>Quantitative Radiology, Verona, Italy</td>
<td>Maxillofacial</td>
<td>15 × 15</td>
<td>110</td>
<td>8.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dentoalveolar - high dose</td>
<td>12 × 8</td>
<td>110</td>
<td>43</td>
</tr>
<tr>
<td>PaX-Uni3D</td>
<td>VATECH, Yongin, Republic of Korea</td>
<td>Upper jaw front region</td>
<td>5 × 5</td>
<td>85</td>
<td>120</td>
</tr>
<tr>
<td>Picasso Trio</td>
<td>VATECH, Yongin, Republic of Korea</td>
<td>Dentoalveolar - high dose</td>
<td>12 × 7</td>
<td>85</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dentoalveolar - low dose</td>
<td>8 × 8</td>
<td>84</td>
<td>169</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dentoalveolar - low dose</td>
<td>8 × 8</td>
<td>84</td>
<td>19.9</td>
</tr>
<tr>
<td>Promax3D</td>
<td>Planmeca Oy, Helsinki, Finland</td>
<td>Dentoalveolar</td>
<td>10 × 7.5</td>
<td>85</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mandible</td>
<td>10 × 7.5</td>
<td>85</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maxilla</td>
<td>10 × 7.5</td>
<td>85</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maxillofacial</td>
<td>14.5 × 13.5</td>
<td>85</td>
<td>48</td>
</tr>
<tr>
<td>Scanora 3D</td>
<td>Soredex, Tuusula, Finland</td>
<td>Dentoalveolar</td>
<td>17 × 17</td>
<td>90</td>
<td>51.5</td>
</tr>
<tr>
<td>SkyView</td>
<td>MyRay, Cefla Dental Group, Imola, Italy</td>
<td>Maxillofacial</td>
<td>8 × 8</td>
<td>70</td>
<td>51.5</td>
</tr>
<tr>
<td>Veraviewepocs 3D</td>
<td>J. Morita, Kyoto, Japan</td>
<td>Dentoalveolar</td>
<td>8 × 8</td>
<td>70</td>
<td>51.5</td>
</tr>
</tbody>
</table>

\(^a\) A selection of clinically applied protocols was made. For all CBCT devices included in this study, additional (high or low dose) protocols may be available.
<table>
<thead>
<tr>
<th>CBCT unit</th>
<th>Field of view</th>
<th>Effective dose (μSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>“Large” CBCT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galileos (Sirona)</td>
<td>15cm x 15cm</td>
<td>84</td>
</tr>
<tr>
<td>iCAT NG</td>
<td>15cm x 13cm</td>
<td>83</td>
</tr>
<tr>
<td>Iluma Elite</td>
<td>21cm x 14cm</td>
<td>368</td>
</tr>
<tr>
<td>NewTom VGI</td>
<td>15cm x 15cm</td>
<td>194</td>
</tr>
<tr>
<td><strong>“Medium” CBCT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kodak 9500</td>
<td>15cm x 8cm</td>
<td>92</td>
</tr>
<tr>
<td>Scanora 3D</td>
<td>10cm x 7.5cm</td>
<td>47</td>
</tr>
<tr>
<td>Accuitomo 170</td>
<td>10cm x 5cm</td>
<td>54</td>
</tr>
<tr>
<td><strong>“Small” CBCT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuitomo 170</td>
<td>4cm x 4cm</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>(lower molar)</td>
<td></td>
</tr>
<tr>
<td>Kodak 9000</td>
<td>5cm x 3.7cm</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>(upper anterior)</td>
<td></td>
</tr>
<tr>
<td>Pax-Uni 3D</td>
<td>5cm x 5cm</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>(upper anterior)</td>
<td></td>
</tr>
</tbody>
</table>

Not all CBCT machines are the same!

For large volumes, higher doses with:
- *Iluma Elite*
- *NewTom VGi*
Lower doses with:
- *Scanora 3D*
- *Galileos*
- *iCAT etc*

SEDENTEXCT studies of effective dose from CBCT


5 CBCT scanners studied (10 protocols)

“10-year old” phantom

“Adolescent” phantom
SEDENTEXCT studies of effective dose from CBCT

Table 3. Imaging protocols and fields of view

<table>
<thead>
<tr>
<th></th>
<th>Adolescent phantom</th>
<th>10-year-old phantom</th>
<th>Field of view</th>
</tr>
</thead>
<tbody>
<tr>
<td>i-CAT NG</td>
<td>(i) Mandible</td>
<td>(i) Mandible</td>
<td>Ø16 cm and</td>
</tr>
<tr>
<td></td>
<td>(ii) Maxilla</td>
<td>(ii) Maxilla</td>
<td>(i) 6 cm height</td>
</tr>
<tr>
<td></td>
<td>(iii) Maxillofacial</td>
<td>(iii) Maxillofacial</td>
<td>(ii) 6 cm height</td>
</tr>
<tr>
<td>NewTom VG</td>
<td>Dental</td>
<td>Dental</td>
<td>(iii) 13 cm height</td>
</tr>
<tr>
<td>Kodak 9000C 3D</td>
<td>Third molar</td>
<td>Maxillary anterior</td>
<td>Ø5 x 3.7 cm height</td>
</tr>
<tr>
<td>ProMax 3D</td>
<td>Dentoalveolar</td>
<td>Dentoalveolar</td>
<td>Ø8 x 8 cm height</td>
</tr>
<tr>
<td>3D Accuitomo 170</td>
<td>(i) Third molar</td>
<td>(i) Maxillary anterior</td>
<td>(i) 4 x 4 cm height</td>
</tr>
<tr>
<td></td>
<td>(ii) Maxilla</td>
<td>(ii) Mandible</td>
<td>(ii) Ø14 cm x 5 cm height</td>
</tr>
<tr>
<td></td>
<td>(iii) Dentoalveolar</td>
<td>(iii) Dentoalveolar</td>
<td>(iii) Ø14 x 10 cm height</td>
</tr>
<tr>
<td></td>
<td>(iv) Maxillofacial</td>
<td>(iv) Maxillofacial</td>
<td>(iv) Ø17 x 12 cm height</td>
</tr>
</tbody>
</table>

From: Theodorakou C et al. Estimation of paediatric organ and effective doses from dental cone beam CT using anthropomorphic phantoms. (Br J Radiol, in press)
Figure 2. Effective dose (\(\mu\text{Gy}\)) for a 10 year old (ATOM model 706-C).
## Radiation dose from CBCT

<table>
<thead>
<tr>
<th>Procedure</th>
<th>*Effective dose (μSv)</th>
<th>Equivalent of natural background radiation in UK (2200 μSv/ year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-oral radiograph</td>
<td>&lt; 1.5</td>
<td>&lt; 1 day</td>
</tr>
<tr>
<td>Cephalometric radiograph</td>
<td>&lt; 6</td>
<td>1 day</td>
</tr>
<tr>
<td>Panoramic radiograph</td>
<td>2.7 – 24</td>
<td>&lt;1 – 4 days</td>
</tr>
<tr>
<td>CBCT (dento-alveolar)</td>
<td>11-674 (median = 61)</td>
<td>2 days – 4 months (median = 10 days)</td>
</tr>
<tr>
<td>CBCT (craniofacial)</td>
<td>30 – 1073 (median = 87)</td>
<td>5 days – 6 months (median = 14 days)</td>
</tr>
<tr>
<td>Multislice CT</td>
<td>280-1410</td>
<td>2 months – 8 months</td>
</tr>
</tbody>
</table>

*Data from Radiation Protection: Cone Beam CT for Dental and Maxillofacial Radiology. Evidence-based Guidelines, 2011. [www.sedentexct.eu](http://www.sedentexct.eu)*
## Effective doses from dental CBCT

<table>
<thead>
<tr>
<th>Technique</th>
<th>Effective dose μSv</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional dental radiography</td>
<td>1-20</td>
</tr>
<tr>
<td>CBCT</td>
<td>20-500</td>
</tr>
<tr>
<td>“Medical” CT</td>
<td>200-2000</td>
</tr>
</tbody>
</table>
## Effective doses from dental CBCT

<table>
<thead>
<tr>
<th>Technique</th>
<th>Effective dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional dental radiography</td>
<td>“X”</td>
</tr>
<tr>
<td>CBCT</td>
<td>10X</td>
</tr>
<tr>
<td>“Medical” CT</td>
<td>100X</td>
</tr>
</tbody>
</table>
CBCT dose estimation

Different parameters to quantify CBCT dose:
1. Anatomical (organ absorbed dose, effective dose)
2. Technical (mAs, CTDI, DAP)

Dose Area Product (DAP) is most relevant & comprehensible dose parameter for quality assurance programmes
CTDI (Computed tomography dose index)

Designed for "medical" CT use

Not ideal for CBCT
- Range of field sizes
- Asymmetrical position of isocentre
- Incomplete rotations
CBCT DI ("Cone Beam Computed Tomography dose index")

Potential CBCT DI explored in SEDENTEXCT project

No single CBCT DI could be defined because of wide variations in CBCT scanners
CBCT Dose Index

Figure 1 Measurement points for Index 1

Figure 2 Measurement points for Index 2
“Dose Area Product” (DAP)

- The product of the dose in the beam multiplied by the area of the beam at that point.
- Calibrated ionisation chamber that integrates the dose across the primary beam (DAP meter)

Unit is mGy.cm²

Ideal method of auditing CBCT dose in dental practices, and to set standards
Summary

“Effective dose” measurements are useful to consider the risks of cancer associated with X-ray exposures.

Effective doses with CBCT vary enormously....not all CBCT machines are the same!

Effective dose is not useful for checking individual dentist’s CBCT equipment. Dose-Area-Product is currently recommended.
Radiation dose optimisation for CBCT
SEDENTEXCT Guidelines

Chapter on “CBCT equipment factors in the reduction of radiation risk to patients”

• 7 guideline statements
CBCT equipment factors in the reduction of radiation risk to patients

• X-ray tube voltage and mAs
• Field of view and collimation
• Filtration*
• Digital detector*
• Voxel size
• Number of basis projections
• Shielding devices

*not under control of operator. Needs input of a medical physics expert
X-ray tube voltage and mAs

Tube voltage (kV) controls number and energy of the X-rays

“exposure” (product of tube current, mA, x exposure time, s) controls number of X-rays

*May be fixed kV, but mA usually adjustable by user*
KiloVoltage and mAs should be adjustable on CBCT equipment and must be optimised during use according to the clinical purpose of the examination, ideally by setting protocols with the input of a medical physics expert.
Optimising X-ray tube voltage and mAs

Excess exposure

“Correct” exposure

Underexposed

Very underexposed
Optimising X-ray tube voltage and mAs
Optimising X-ray tube voltage and mAs
Optimising X-ray tube voltage and mAs

Children and smaller individuals

Diagnostic tasks not requiring a very high level of detail (e.g. implants*)


Dose optimisation: practical experience

Survey of six months workload of a hospital-based CBCT unit
[4 by 4cm limited volume Accuitomo CBCT]

<table>
<thead>
<tr>
<th></th>
<th>&lt; 21 years</th>
<th>&gt;21 years female</th>
<th>&gt;21 years male</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median kV</td>
<td>85</td>
<td>87</td>
<td>90</td>
</tr>
<tr>
<td>Median mA (fixed “s”)</td>
<td>3.5</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
Number of basis projections

Reduction in number of basis images

Fewer basis images means lower exposure time used

Number of basis projections

Reduction in number of basis images

Fewer basis images means lower exposure time used

Research studies should be performed to assess further the effect of the number of projections on image quality and radiation dose

GP
Field of view and collimation

Multipurpose dental CBCT equipment should offer a choice of volume sizes and examinations must use the smallest that is compatible with the clinical situation if this provides less radiation dose to the patient.
Field of view and collimation

Limiting the FoV size to the volume of interest

- Steep drop in dose outside primary beam

Changing the position of the FoV to avoid crucial organs

- Organs to avoid if possible: thyroid & salivary glands
“Resolution” and voxel size

Spatial Resolution is related to the exposure factors used.

“Higher resolution” options achieved by increased exposure (mAs or more basis images).

Multipurpose dental CBCT equipment should offer a choice of voxel sizes and examinations should use the largest voxel size (lowest dose) consistent with acceptable diagnostic accuracy.
Shielding

Useful for primary radiation (and external scatter)

Thyroid only practicable application in dental CBCT

Should be no need for abdominal lead protection in CBCT

Summary

Several parameters determine the patient dose associated with a CBCT examination.

Some can be adjusted by the operator, some are fixed by the manufacturer and some can be changed with the advice of a Medical Physics Expert.

There is always a trade-off between radiation dose and image quality; the difficult choice is identifying the compromise......
Quality Assurance and Quality Control for CBCT
Quality in radiology

Radiological Quality Assurance (QA) can be defined as “all those planned and systematic actions necessary to provide adequate confidence that a structure, system, component or procedure will perform satisfactorily complying with agreed standards”

Quality in radiology

A radiological Quality Assurance (QA) Programme is the “framework” or “organised effort” which is devised to achieve quality assurance.

Quality Control

Administrative procedures to verify that:

• the quality control techniques are performed properly and according to a planned timetable,
• the results of these techniques are evaluated promptly and accurately,
• the necessary corrective measures are taken in response to these results
Chapter on “Quality standards and quality assurance” with 8 guideline statements
Quality Assurance Programme for CBCT in dentistry

- Performance of the X-ray tube and generator (X-ray equipment performance)
- Quantitative assessment of image quality
- Display screen performance
- Patient dose assessment
- Clinical image quality assessment
- Clinical audit
1. Performance of the X-ray tube and generator (X-ray equipment performance)

Testing of dental CBCT should include a critical examination and detailed acceptance and commissioning tests when equipment is new and routine tests throughout the life of the equipment. Testing should follow published recommendations and a Medical Physics Expert should be involved.
1. Performance of the X-ray tube and generator (X-ray equipment performance): *Critical examination*

A critical examination of the installation is required to ensure that all safety features are correctly installed and functioning and that adequate protection is provided to the operator and anyone else who may be in the area.

Advice of a Medical Physics Expert is valuable
1. Performance of the X-ray tube and generator (X-ray equipment performance): *Acceptance and Commissioning testing*

- testing of equipment performance parameters
- acquiring base line values for future routine tests
- verification of how the systems are pre-programmed for use in practice

Tests normally performed by a Medical Physics Expert
1. Performance of the X-ray tube and generator (X-ray equipment performance): *Acceptance and Commissioning testing*

- X-ray tube output
- Voltage consistency and accuracy
- Filtration
- Radiation field of view
- Leakage

*Repeatability and reproducibility of X-ray tube output*
1. Performance of the X-ray tube and generator (X-ray equipment performance): Acceptance and Commissioning testing

- X-ray tube output
- Voltage consistency and accuracy
- Filtration
- Radiation field of view
- Leakage

Accuracy, repeatability and reproducibility of kV

$kV$ divider
1. Performance of the X-ray tube and generator (X-ray equipment performance): *Acceptance and Commissioning testing*

- X-ray tube output
- Voltage consistency and accuracy
- **Filtration**
- Radiation field of view
- Leakage

*Can be estimated by measuring the “Half Value Layer” (the thickness of aluminium required to reduce the intensity of the incident X-ray beam by half)*
1. Performance of the X-ray tube and generator (X-ray equipment performance): *Acceptance and Commissioning testing*

- X-ray tube output
- Voltage consistency and accuracy
- Filtration
- Radiation field of view
- Leakage

*Confirms beam field size and alignment is in accordance with the manufacturer’s nominal field of view*
1. Performance of the X-ray tube and generator (X-ray equipment performance): *Acceptance and Commissioning testing*

- X-ray tube output
- Voltage consistency and accuracy
- Filtration
- Radiation field of view
- Leakage
1. Performance of the X-ray tube and generator (X-ray equipment performance): *Routine testing*

The tests conducted as part of Acceptance and Commissioning testing should be repeated at regular intervals.

National requirements may dictate a frequency, but typically these tests should be repeated on an annual basis.

Tests normally performed by a Medical Physics Expert.
Quality Assurance Programme for CBCT in dentistry

- Performance of the X-ray tube and generator (X-ray equipment performance)
- Quantitative assessment of image quality
- Display screen performance
- Patient dose assessment
- Clinical image quality assessment
- Clinical audit
2. Quantitative assessment of image quality

Objective assessment of image quality requires a QA “phantom” (test object)

May be supplied by the equipment manufacturer

Other phantoms are commercially available

Phantoms for conventional CT are not ideal for CBCT QA

Tests can be performed by clinical staff or by a Medical Physics Expert

Leeds Test Objects Ltd.
2. Quantitative assessment of image quality

2. Quantitative assessment of image quality

A PMMA cylinder (160 mm diameter) with recesses to house test inserts (fig. 1). Within the body of the cylinder are features for the following tests:

**Noise/Uniformity**
- The lower section of the phantom is uniform PMMA (density 1.20 +/- 1.00%)

**Geometric Distortion**
- An array of 2.0 mm diameter, 3.0 mm deep Air gaps are uniformly pitched through one slice of the cylinder.

Test inserts are included to perform the following measurements:

**Spatial Resolution**
- Line Spread Function (LSF) - PMMA/PTFE interface (fig. 2)
- Point Spread Function (PSF) - 0.25mm diameter stainless steel wire suspended in air (fig. 3)
- LP/mm - alternating Aluminium/polymer (XY) (1.0 to 5.0 LP/mm) (fig. 4)
- LP/mm - alternating Aluminium/polymer (Z) (1.0 to 5.0 LP/mm) (fig. 5)

**Contrast Resolution** (fig. 6)
- 1.0, 2.0, 3.0, 4.0, 5.0 mm diameter PTFE, delrin, LDPE, Aluminium, Air, Water (PMMA) rods suspended in PMMA

**Pixel Integrity** (fig. 7)
- 10.0 mm diameter PTFE, delrin, LDPE, Aluminium, Air, Water (PMMA) rods suspended in PMMA

**Beam Hardening Artefacts** (fig. 8)
- A line of three 5.0 mm diameter rods of Ti suspended in PMMA

**Blank PMMA Insert** (fig. 9)
2. Quantitative assessment of image quality
2. Quantitative assessment of image quality

Measurements:

- Image density values
- Contrast detail
- Uniformity and noise
- Spatial resolution
- Geometric accuracy
- Artefacts

Measure mean (and standard deviation) pixel grey scale value(s) in a specified region(s) of the phantom
2. Quantitative assessment of image quality

Measurements:

• Image density values
• **Contrast detail**
• Uniformity and noise
• Spatial resolution
• Geometric accuracy
• Artefacts

*Tests a system’s ability to display details of known varying contrast*
2. Quantitative assessment of image quality
2. Quantitative assessment of image quality

Measurements:

- Image density values
- Contrast detail
- Uniformity and noise
- Spatial resolution
- Geometric accuracy
- Artefacts

Image a uniform part of the phantom: homogenous material

Noise expressed in terms of SD of grey levels within ROIs selected in test objects with uniform densities
2. Quantitative assessment of image quality

Measurements:
- Image density values
- Contrast detail
- Uniformity and noise
- **Spatial resolution**
- Geometric accuracy
- Artefacts

The ability of the system to resolve two objects placed closely to each other

Phantoms contain bar patterns of various spatial frequencies
• A line pair is a pair of equal-sized bars (aluminium)
• Frequency: objects closely spaced means high frequency (1 to 5 l.p. mm\(^{-1}\) in SEDENTEX CT phantom)
• The finest bar pattern that can be distinguished determines the highest spatial frequency
2. Quantitative assessment of image quality

Measurements:

- Image density values
- Contrast detail
- Uniformity and noise
- Spatial resolution
- Geometric accuracy
- Artefacts

Where quantitative test tools are available, measure distances and angles across a variety of the objects within the phantom.

Compare the measured values with known distances and angles.
2. Quantitative assessment of image quality

Measurements:

• Image density values
• Contrast detail
• Uniformity and noise
• Spatial resolution
• Geometric accuracy
• Artefacts
2. Quantitative assessment of image quality

From:


Fig. 3. Axial slices of titanium and lead inserts for selected CBCT and MSCT protocols. An automatic window/level setting was chosen in most cases; manual window/level adjustment was performed if the automatic setting was suboptimal. Visual evaluation of these artifacts should be avoided.
Quality Assurance Programme for CBCT in dentistry

- Performance of the X-ray tube and generator (X-ray equipment performance)
- Quantitative assessment of image quality
- Display screen performance
- Patient dose assessment
- Clinical image quality assessment
- Clinical audit
3. Display screen performance

Great CBCT system
+ Bad monitor
= Bad CBCT scans in practice
3. Display screen performance

A suitable test pattern, such as an AAPM TG18 or SMPTE image, should be installed on the computer and viewed on the monitor, which should be clean.
3. Display screen performance

• It should be ensured that all distinct greyscale levels on the test pattern can be individually resolved.

• It should be ensured that all of the bars on each of the resolution patterns on the AAPM TG18 or SMPTE test image can be clearly resolved.
Quality Assurance Programme for CBCT in dentistry

- Performance of the X-ray tube and generator (X-ray equipment performance)
- Quantitative assessment of image quality
- Display screen performance
- Patient dose assessment
- Clinical image quality assessment
- Clinical audit
4. Patient dose assessment

We cannot use effective dose to monitor patient dose in everyday clinical practice.

We need a quick and easy way of recording something which represents “dose” to patients.

For CBCT “Dose-Area-Product” (DAP) seems to be the best option.

- The product of the dose in the beam multiplied by the area of the beam at that point.
4. Patient dose assessment

Manufacturers of dental CBCT equipment should provide a read-out of Dose-Area-Product (DAP) after each exposure.
4. Patient dose assessment

• Diagnostic Reference Levels: dose levels in medical radiodiagnostic practices for typical examinations for groups of standard-sized patients. Derived from large audit samples.

Figure 6: Showing distribution of DWP values in panoramic x-ray sets in the 2005 study

Health protection Agency UK data
4. Patient dose assessment

• There is insufficient audit data on CBCT to set a formal DRL at the present time
• Instead, an “achievable dose” has been set as a provisional measure
• Based upon CBCT of an adult patient being assessed for a single upper molar implant

Until further audit data is published, the panel recommend the adoption of an achievable Dose Area Product of 250 mGy cm$^2$ for CBCT imaging for the placement of an upper first molar implant in a standard adult patient.

In the future, an “achievable dose”, and eventually DRL, should also be set for paediatric CBCT
4. Patient dose assessment

Figure 2. DAP values for placement of upper first molar implant in standard adult male patient (dimensions of irradiated area shown in cm)

Quality Assurance Programme for CBCT in dentistry

- Performance of the X-ray tube and generator (X-ray equipment performance)
- Quantitative assessment of image quality
- Display screen performance
- Patient dose assessment
- Clinical image quality assessment
- Clinical audit
Assessment of the clinical quality of images should be a part of a quality assurance programme for CBCT GP.
5. Clinical image quality assessment

The use of reference images

• helps to guard against a gradual drift away from optimal quality which may occur in practice over time
• A CBCT scan dataset of excellent quality is used as a reference, against which everyday clinical scans can be assessed.
Quality Assurance Programme for CBCT in dentistry

- Performance of the X-ray tube and generator (X-ray equipment performance)
- Quantitative assessment of image quality
- Display screen performance
- Patient dose assessment
- Clinical image quality assessment
- Clinical audit
6. Clinical audit

“a quality improvement process that seeks to improve patient care and outcomes through systematic review of care against explicit criteria and the implementation of change”
6. Clinical audit

1. Identify issue: CBCT clinical image quality

Some problems are obvious, easily identified and can be explained as isolated cases

Other problems can become “normal” and begin to be ignored – this is not acceptable
6. Clinical audit

1. Identify issue:
   CBCT clinical image quality

2. Set standards

<table>
<thead>
<tr>
<th>Quality grade</th>
<th>Quality standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptable CBCT</td>
<td>≥ 95%</td>
</tr>
<tr>
<td>examinations</td>
<td></td>
</tr>
<tr>
<td>Unacceptable CBCT</td>
<td>≤ 5%</td>
</tr>
<tr>
<td>examination</td>
<td></td>
</tr>
</tbody>
</table>

As a minimum target, no greater than 5% of CBCT examinations should be classified as “unacceptable”. The aim should be to reduce the proportion of unacceptable examinations by 50% in each successive audit cycle.
# Clinical Quality Standards for CBCT images

## A. Adequate patient preparation, positioning and instruction
- No removable metallic foreign bodies which might produce scan artefacts (e.g. earrings, spectacles, dentures)
- No motion artefacts
- No evidence of incorrect positioning of imaging guides/stents (e.g. air gap due to incorrect seating of the stent)
- Where fixed, metallic, restorations are in the teeth, no artefacts overlying the area of primary interest.

## B. Correct anatomical coverage
- Evidence that the smallest Field of View available on the equipment has been used, consistent with the clinical application.
- The primary area of interest at or near the centre of the Field of View.
- All of the area of interest included in the scan volume.

## C. Adequate exposure factors used
- Absence of significant image noise, low density and contrast

---

1. It is recognised that it may not always be possible to exclude restoration-related artefacts, but there should be evidence that every effort has been made to limit their impact (e.g. by careful orientation of the occlusal plane during positioning).
2. e.g. single tooth or single implant site. It is recognised that where multiple implant sites or larger structures are being imaged, not all can be central in the scan volume.
6. Clinical audit

1. Identify issue:
   CBCT clinical image quality

2. Set standards

3. Observe practice and collect data

4. Implement change

5. Re-audit!
<table>
<thead>
<tr>
<th>Test</th>
<th>Priority</th>
<th>Level of expertise*</th>
<th>Suggested frequency</th>
<th>Action levels**</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>X-ray tube and generator</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output repeatability</td>
<td>Essential</td>
<td>MPE</td>
<td>12 monthly</td>
<td>Mean ±10%</td>
</tr>
<tr>
<td>Output reproducibility</td>
<td>Essential</td>
<td>MPE</td>
<td>12 monthly</td>
<td>Baseline ±10%</td>
</tr>
<tr>
<td>Filtration</td>
<td>Essential</td>
<td>MPE</td>
<td>When new, if output changes or tube head dismantled</td>
<td>&lt; 2.5mm aluminium (of which 1.5mm should be permanent)</td>
</tr>
<tr>
<td>Tube potential</td>
<td>Essential</td>
<td>MPE</td>
<td>12 monthly</td>
<td>&gt; ±5% of intended kV</td>
</tr>
<tr>
<td>Field size and alignment</td>
<td>Essential</td>
<td>MPE</td>
<td>12 monthly</td>
<td>&gt;10% expected field size</td>
</tr>
<tr>
<td>Leakage</td>
<td>Essential</td>
<td>MPE</td>
<td>When new and if damage suspected</td>
<td>&gt; 1000µGy hr-1 at maximum tube rating.</td>
</tr>
<tr>
<td><strong>Quantitative image Quality</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Image density values</td>
<td>Recommended</td>
<td>In house/MPE</td>
<td>Monthly</td>
<td>&gt;10% from baseline</td>
</tr>
<tr>
<td>Uniformity and artifacts</td>
<td>Essential</td>
<td>In house</td>
<td>Monthly</td>
<td>Visible artefacts on the image or &gt;±10% of the mean</td>
</tr>
<tr>
<td>Noise</td>
<td>Recommended</td>
<td>In house/MPE</td>
<td>12 monthly</td>
<td>&gt; ±10% from baseline</td>
</tr>
<tr>
<td>Limiting resolution</td>
<td>Essential</td>
<td>In house/MPE</td>
<td>12 monthly</td>
<td>&gt; ±20% from baseline</td>
</tr>
<tr>
<td>Contrast detail</td>
<td>Recommended</td>
<td>In house/MPE</td>
<td>12 monthly</td>
<td>Dependent on method used.</td>
</tr>
<tr>
<td>Geometrical accuracy</td>
<td>Essential</td>
<td>In house/MPE</td>
<td>12 monthly</td>
<td>Within ±0.5mm and ±2º</td>
</tr>
<tr>
<td><strong>Display specific</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General condition</td>
<td>Essential</td>
<td>In house</td>
<td>Monthly</td>
<td>Failure to resolve different contrasts in test pattern/ not consistent between monitors</td>
</tr>
<tr>
<td>Monitor resolution</td>
<td>Recommended</td>
<td>In house</td>
<td>Monthly</td>
<td>Not consistent with baseline image</td>
</tr>
<tr>
<td><strong>Patient dose</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient dose index</td>
<td>Recommended</td>
<td>MPE</td>
<td>12 monthly</td>
<td>Outside ±15% of manufacturer’s specification</td>
</tr>
<tr>
<td>Patient dose audit</td>
<td>Essential</td>
<td>In house/MPE</td>
<td>At least 3 yearly</td>
<td>&gt; national or international reference level</td>
</tr>
</tbody>
</table>

SEDENTEXCT Guidelines, 2011
CBCT Suspension levels

http://www.neyhqarc.nhs.uk/rp162/Home.aspx

RP162 - Radiation criteria for acceptability of medical radiological equipment used in diagnostic radiology, nuclear medicine and radiotherapy

The Project
In 2010, the European Commission published a consultation. Following the consultation, the ECDMRF was set up.

This project’s main objectives are to process the outcomes of the consultation and propose new guidelines for the protection of patients and operators.
### RP162 CBCT Suspension levels (final draft)

<table>
<thead>
<tr>
<th>Physical parameter</th>
<th>Suspension level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube voltage accuracy</td>
<td>Maximum deviation &gt;± 10%</td>
</tr>
<tr>
<td>Accuracy of indicated Dose Parameters</td>
<td>Dose &gt;± 20% indicated doses</td>
</tr>
<tr>
<td>Radiation output repeatability and reproducibility</td>
<td>DAP &gt;2 x “Achievable dose” (or Diagnostic Reference Level when established), after all dose optimisation strategies have been exhausted by the user in conjunction with the Medical Physics Expert.</td>
</tr>
<tr>
<td>*CTDI – free in air</td>
<td>Does not meet manufacturer’s specification or Baseline &gt;± 40%</td>
</tr>
<tr>
<td>Field of View</td>
<td>Field larger than the size of the solid detector housing</td>
</tr>
<tr>
<td>Image noise</td>
<td>Baseline &gt;± 25%</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>&lt; 1 lp/mm (in high resolution mode)</td>
</tr>
<tr>
<td>Image density values</td>
<td>Does not meet manufacturer’s specification or Baseline &gt;± 25%</td>
</tr>
<tr>
<td>Artefacts</td>
<td>Any artefacts likely to impact on clinical diagnosis</td>
</tr>
</tbody>
</table>
Summary

Quality assurance (QA) is aimed at achieving acceptable quality at the lowest achievable dose.

A QA programme, incorporating a standard series of quality control tests, is an essential part of this programme.

QA must involve the dentist and a medical physics expert working as a team.
Staff protection
Staff protection

It is essential that a Qualified Expert* is consulted over the installation and use of CBCT to ensure that staff dose is as low as reasonably achievable and that all relevant national requirements are met.

“Qualified expert” = medical physicist
Staff protection

Factors affecting staff doses

Exposure factors (kV, mAs, field of view, full/partial rotations)

Increasing the exposure factors results in increased scattered radiation
Staff protection

Factors affecting staff doses

Primary beam is considered to be fully attenuated by the patient and the detector.

Scattered x-ray dose is the main contributor to occupational exposure; varies significantly with different units.

Maximum dose at 1 metre due to scattered radiation varies between 2 to 47 µSv per scan, compared with intraoral and panoramic radiography scatter doses of less than 1 µSv per exposure.
Staff protection

Practical control measures

Time
Minimization of the time exposed to any source of radiation
Staff protection

Practical control measures

Distance

Scatter radiation decreases with distance according to the inverse square law: double the distance, the dose decreases by a factor of 4.
Staff protection

Practical control measures for external radiation

Shielding
Shielding in the barriers of the room & shielding devices between the operator and the source

“The clinic must make sure that the radiation dose on the outside of the x-ray room does not exceed 0,25 mSv/year”
(In Norway: StrålevernInfo 8:10)
Staff protection

Shielding:
In order to calculate the shielding in the barriers the following factors should be taken into account:
• Dose constraint (0.25mSv/year in Norway)
• Workload (patients scanned/week)
• Dose rate per scan (worst case scenario)
• Tube voltage
• Barrier to patient distance

Input from a Qualified Expert needed
Staff protection

<table>
<thead>
<tr>
<th>Scatter per scan (µSv)</th>
<th>Patients per week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>8</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>12</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>16</td>
<td>0.5 mm</td>
</tr>
</tbody>
</table>

Summary of shielding requirements at 1 m for dose constraint of 0.3 mSv per annum
Staff protection

Warning lights:
Warning lights and signs should be installed outside the room

Exposure control:
For machines which require software authorisation, the computer should be placed such that full view of the room is ensured. For exposure switches which are placed outside the room, they should be key controlled to prevent unauthorised use
Staff protection

Personal monitoring
• Need for personal monitoring must be considered in the prior risk assessment
• If the operating situation is such that an exposure cannot be initiated unless the operator is standing behind a shielded door or window, occasional monitoring is suggested
• Otherwise, routine monitoring is recommended

The provision of Personal Monitoring should be considered
Summary

Staff must have received adequate training

Patient dose optimisation should help with staff dose optimisation

Policies should be established that eliminate staff risk from radiation

Shielding is likely to be required with CBCT installations

INVolVEMENT OF A MEDICAL PHYSICS EXPERT PRIOR TO EQUIPMENT INSTALLATION IS ESSENTIAL TO OPTIMISE STAFF DOSE
SEDENTEXCT: Guidelines and evidence-based use of CBCT

Keith Horner
Acknowledgement: The research leading to these results has received funding from the European Atomic Energy Community’s Seventh Framework programme FP7/ 2007-2011 under grant agreement no. 212246 (SEDENTEXCT: Safety and Efficacy of a New and Emerging Dental X-ray Modality).