Dose metrics and practical dose measurements for dental and maxillofacial CBCT

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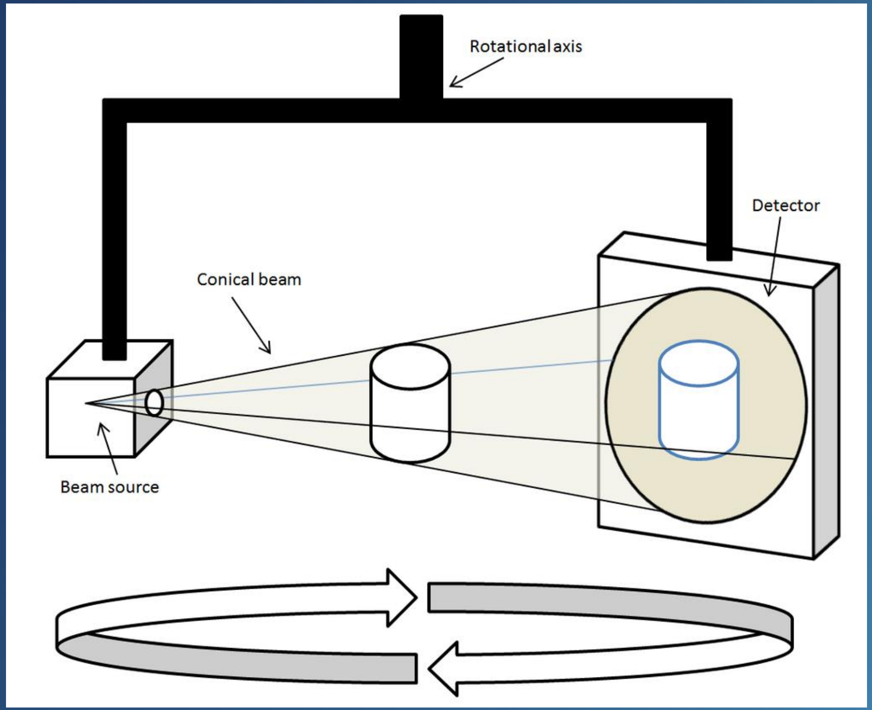
Outline

- Introduction
- Dose measurement options for CBCT
  - CTDI
  - CBDI
  - DAP/KAP
  - Air kerma to reference point
  - Dose over the diameter of the field of view (D_{FOV})
- Dosimetry recommendations by various expert groups
- AAPM TG261 perspective and recommendations

Introduction

- CBCT geometry is somewhat unique
  - For dental/OMS applications
    - Horizontal gantry
    - Stationary patient
    - Wide x-ray beam
      - Not a cone, really a rectangular pyramid
    - Offset geometry (non-symmetric) is possible



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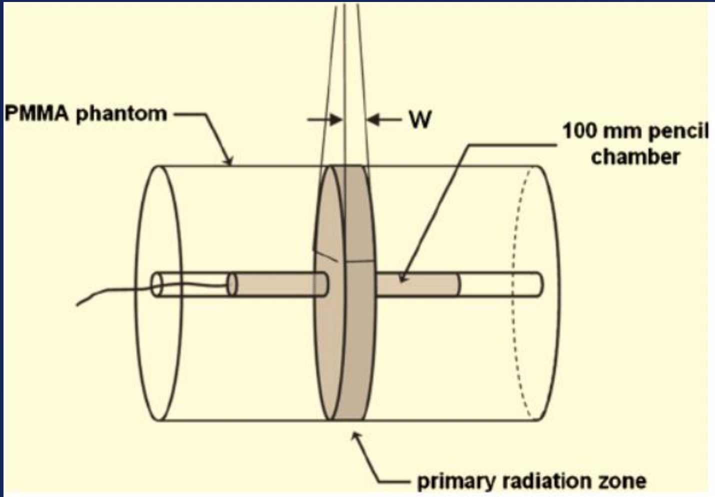
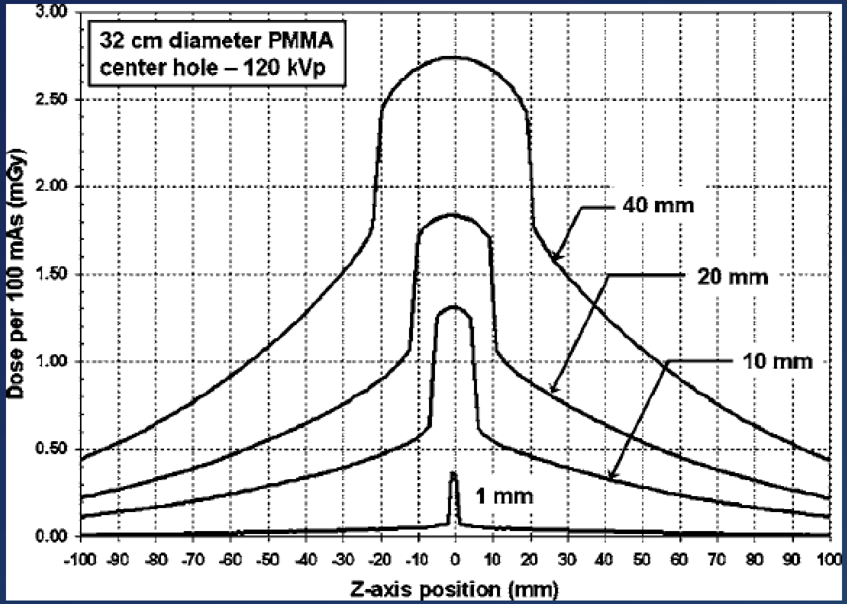
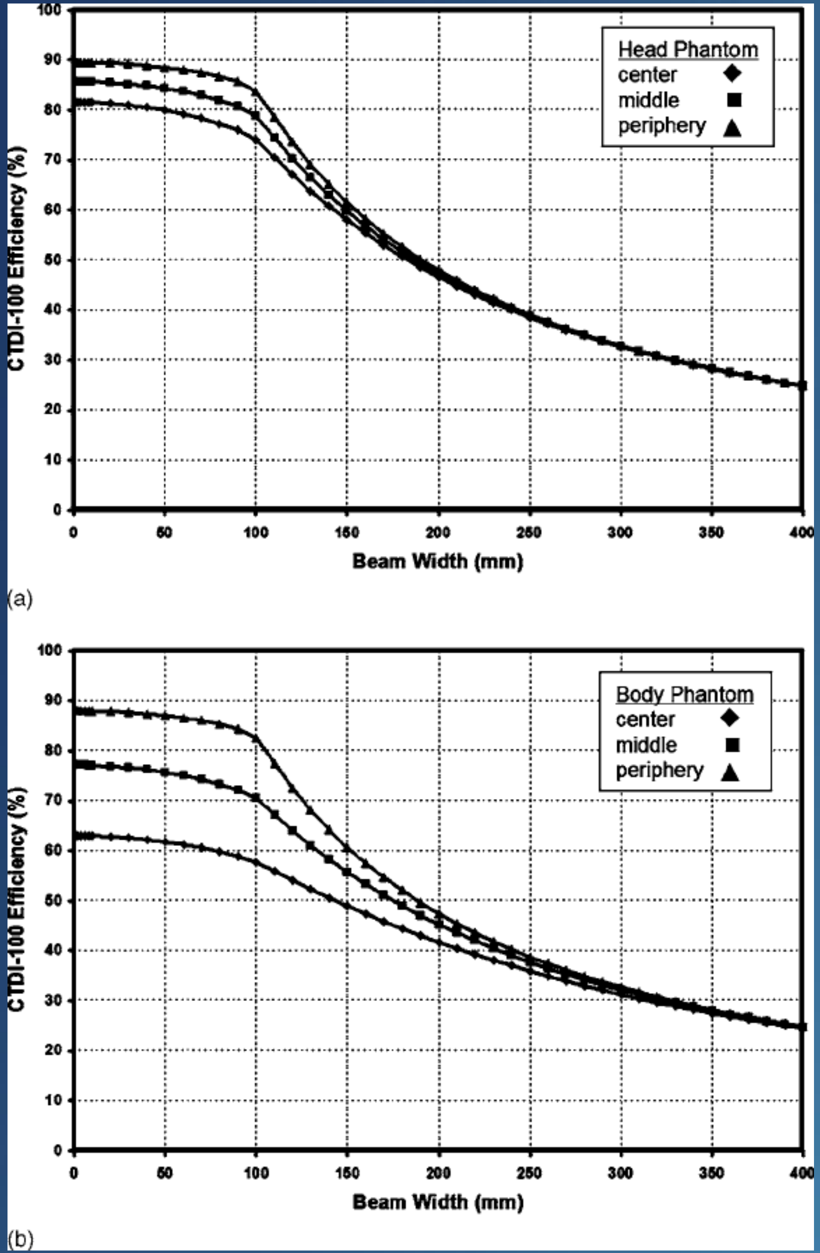
The CBCT dosimetry problem







Boone, Med Phys 34(4) 2007

The CBCT dosimetry problem

- $CTDI_{100}$ provided a good estimation of patient dose for narrow radiation beam widths and was generally accepted
  - Reliable approximation of patient dose under clinical scan conditions
  - Reliable measure of radiation output for fan-beam CT scanners
  - 100 mm is a reasonable integration range if the beam width and most of scatter tails are contained within 100 mm
  - For wide beams and extended tails > 100mm, the 100mm integration length is inadequate to capture full dose profile
  - For wide beams, CTDI phantoms (15 cm wide) are insufficient to achieve scatter equilibrium at center of phantom

Mori et al, Med Phys 32(4) 2005

The CBCT dosimetry problem

- Longer phantom and dose integration length
  - >300 mm long phantom proposed (Mori)
  - Long ionization chamber or small chamber with translation
  - Not practical for dental CBCT
- CTDI is desirable because it allows intercomparison with MDCT

Mori et al, Med Phys 32(4) 2005

“Cone Beam Dose Index” (CBDI)

- Described by Amer at al (BJR 2007)
  - $\text{CTDI}_{100} = \frac{1}{L}\int_{-50mm}^{+50mm} D(z)dz$
    - D(z) = dose profile
    - L = nominal beam width (=NxT in MDCT)
    - CTDI100 = CTDI for Z=100
    - Aka $\text{CTDI}_{\text{IEC2.0}}$
  - $\text{CBDI} = \frac{1}{\min\{L,100\}}\int_{-50mm}^{+50mm} D(z)dz$
    - L = nominal beam width
    - CBDI reasonably estimates dose in the central 100 mm of the FOV along the z-axis
    - Aka $\text{CTDI}_{\text{IEC3.0}}$, “average dose”

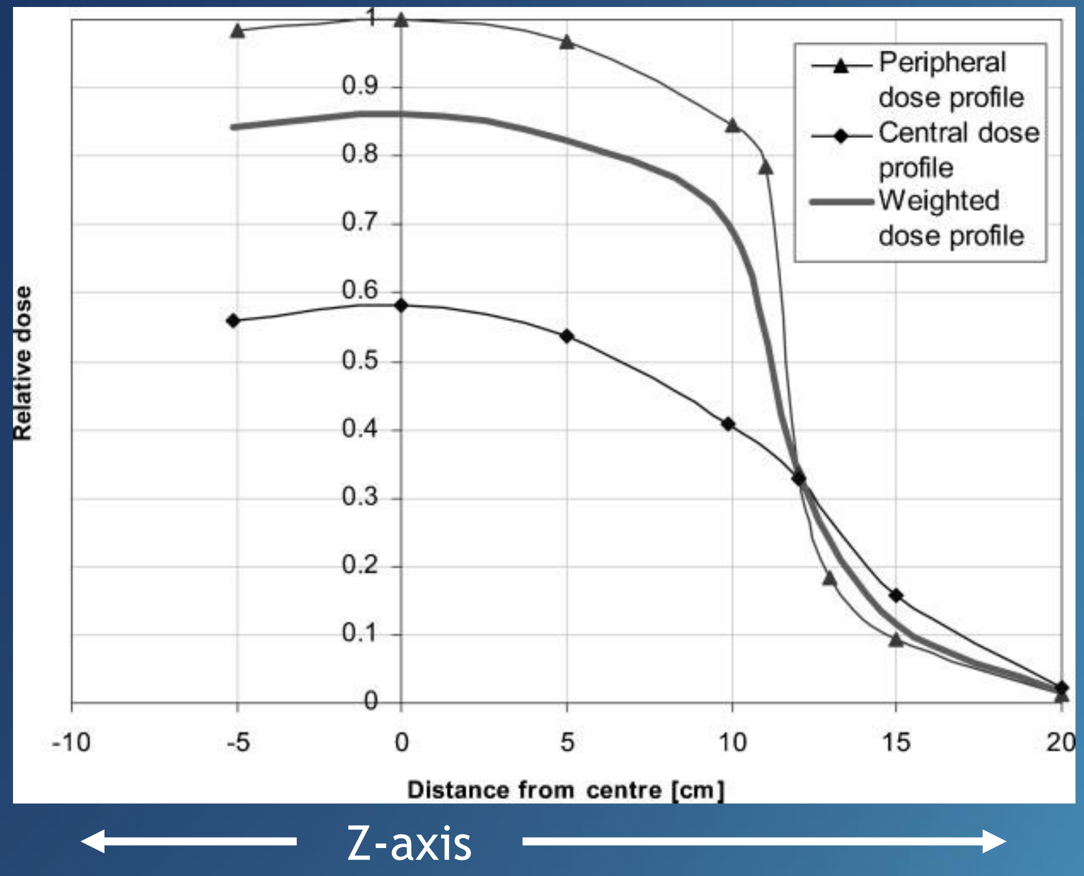
Amer et al, BJR pp.476-482, 2007

“Cone Beam Dose Index” (CBDI)

- Initially adopted by IEC (IEC 60601-2-44 Edition 3)
- Known as $CTDI_{w,IEC3.0}$ (2009)
- Desire to “preserve” the intent of CTDI as an index representing the dose profile integral
- Known as $CTDI_{w,IEC3.0}$ is not accurate for very wide beam widths
- $CTDI_{IEC3.1}$ (2012) uses conventional CTDI up to 40mm, and 20 mm reference beam width and scaling by ratio of free-in-air measurements of nominal to the reference beam (two-tiered approach)
    - Also adopted by IAEA in Human Health Report No 5 (2011)

"Cone Beam Dose Index" (CBDI)

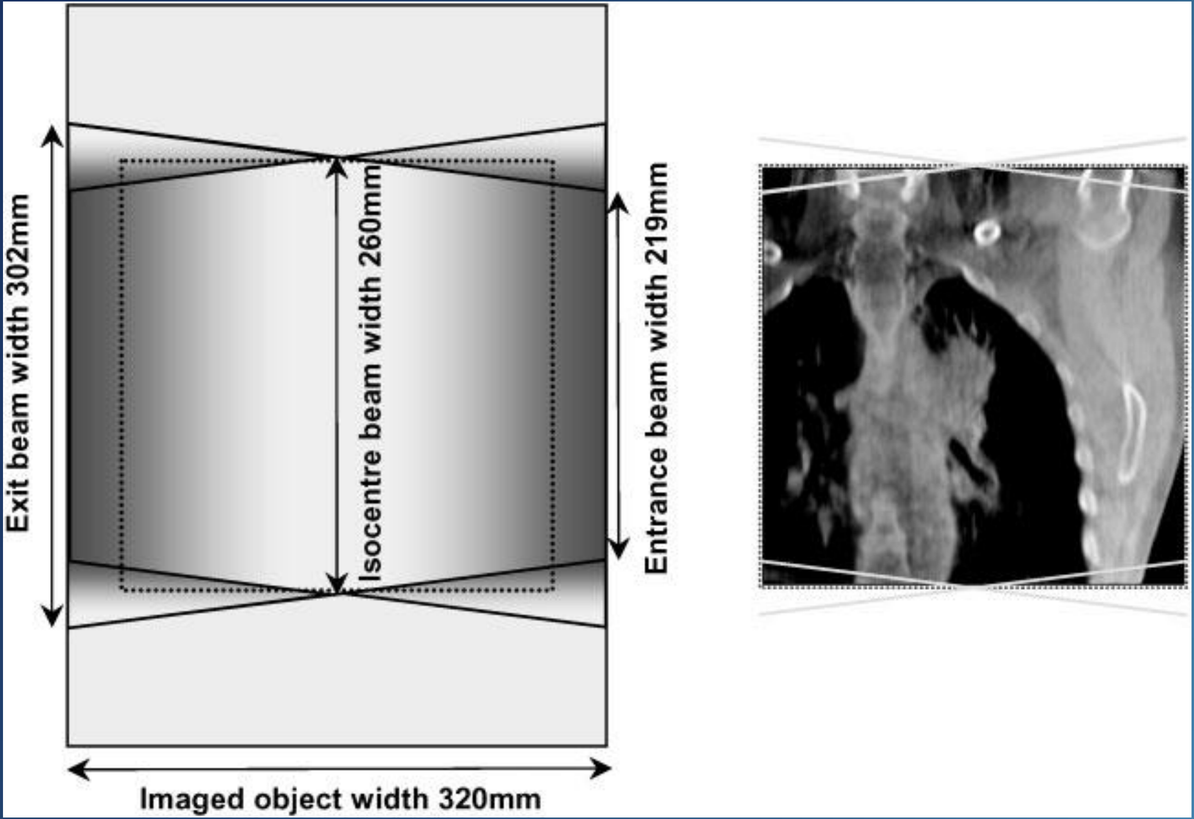
- Amer showed that for a 26 cm wide beam, 10 cm of dose integration (-5 - +5 cm) gives a conservative measure of weighted dose across the imaged volume
  - Measured in a 32 cm CTDI phantom with 15 cm scatter material added to each end



Amer et al, BJR pp.476-482, 2007

Reduction of dose at the extremes of the cone angle

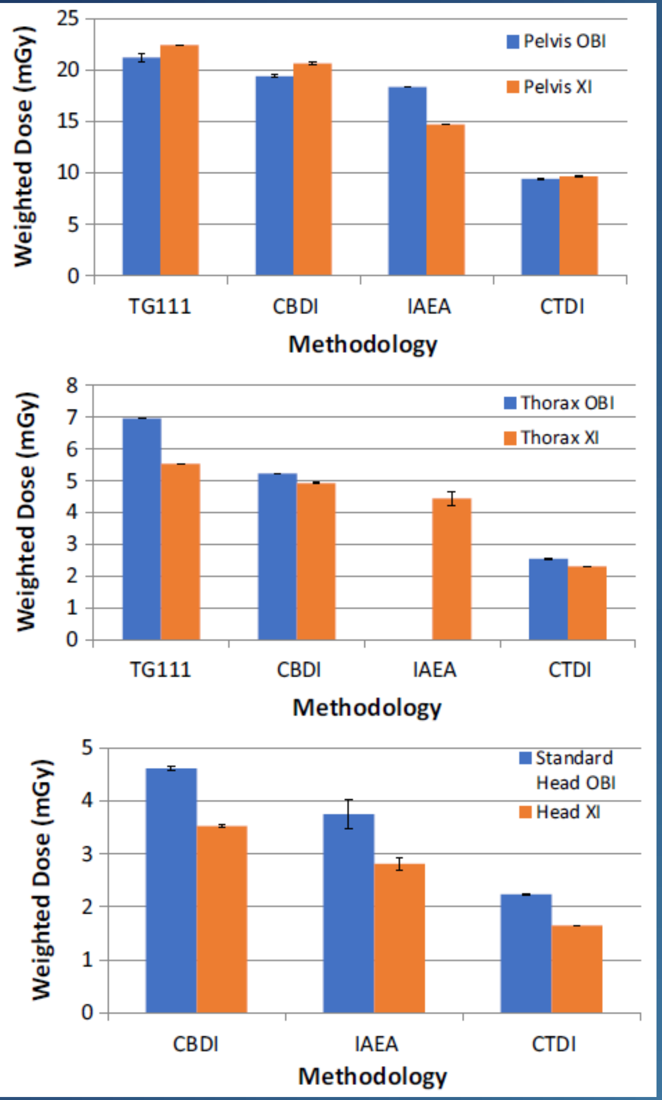
- Nominal 26 cm beam width (isocenter)
- For 32 cm diam phantom
  - Entrance width = 21.9 cm
  - Exit width = 30.2 cm



Comparison of dosimetry methods for CBCT

- Buckley (2017) compared 4 methodologies for measuring CT dose in CBCT (Varian OBI and XI CBCT imaging systems)
  - CBDI (aka $CTDI_{IEC3.0}$)
  - IAEA Report 5 (aka $CTDI_{IEC3.1}$)
  - AAPM TG111
    - 45 cm long cylindrical phantom
    - 0.6 cc "Farmer" ionization chamber
  - Conventional CTDI

Buckley et al, J Appl Clin Med Phys, 19(1) 2018



Beam width
21 cm
21 cm
18-21 cm

Comparison of dosimetry methods for CBCT

- CBDI compares well with IAEA and TG111 at beam widths ≥10 cm
- Investigators normalized by 10 cm at all beam widths
  - Did not use min{L,100}
- CBDI = CTDI at beam widths ≤ 10 cm

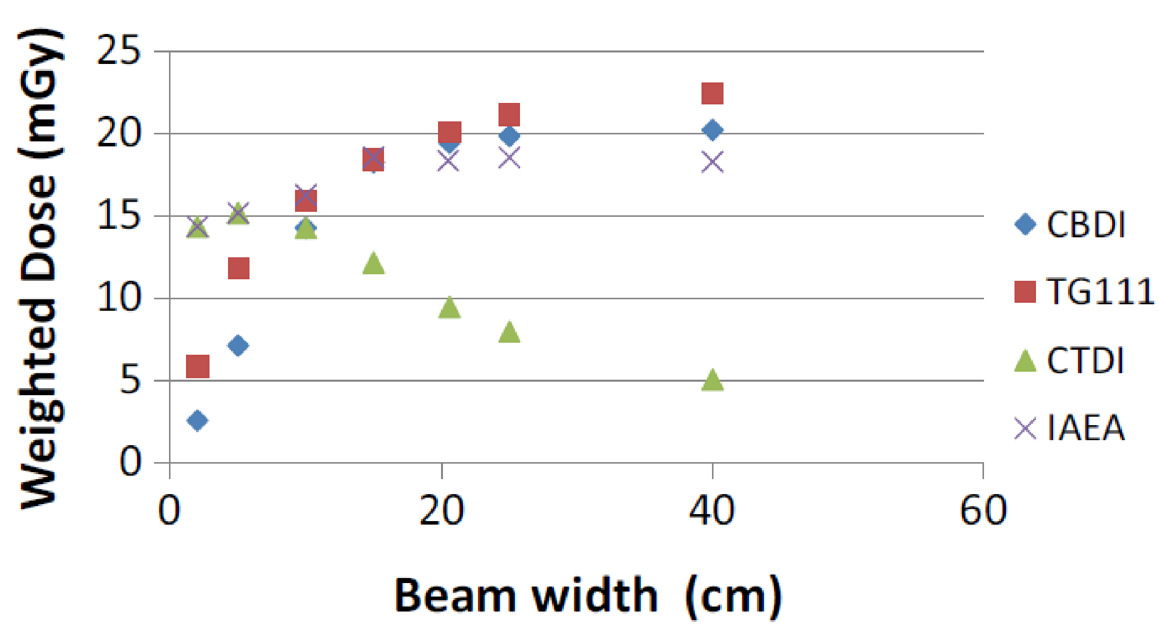


Fig. 5. Weighted CTDI, CBDI, IAEA, and TG111 methodologies for increasing S–I collimation. The beam width was increased from 2 cm to 40 cm and was acquired on the OBI pelvis CBCT mode.

Buckley et al, J Appl Clin Med Phys, 19(1) 2018

Dose-Area Product (DAP) / Kerma-Area Product (KAP)

- UK requires Dose Reference Levels (DRLs) and Achievable Doses (ADs) as an “aid to optimization”
  - The DRL/AD dose metric is defined to be DAP
  - Most (all?) dental CBCT units report DAP
- UK requires field testing of CTDI only when it is included in mfgr’s equipment specification

Measurement of DAP/KAP in the clinic

- “Uniform” beam
  - No bowtie filter, only heel effect
  - “Point dose” measurement at center of field
  - Field size measurement
    - Radiochromic film, CR cassette, or beam edge sensing device
- Non-uniform beam (eg, bow-tie filter)
  - DAP meter
  - “Extended dose” radiation measurement
    - CT pencil chamber at exit window
  - Field size measurement
    - Radiochromic film, CR cassette, or beam edge sensing device
- See Gingold et al e-Poster PO-GeP-I-70 at AAPM/COMP 2020

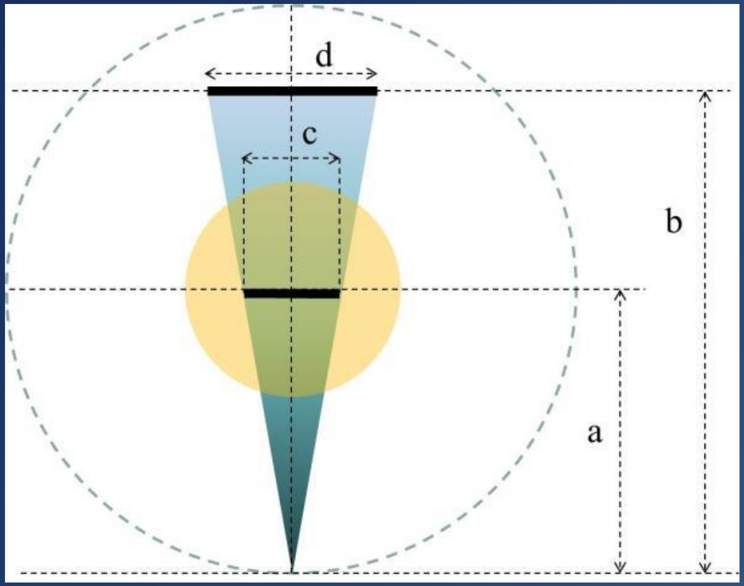
Air Kerma to a reference point

- Reference point is often the entrance of the image receptor, or isocenter
  - Required to be reported in Germany
  - Simple and convenient
  - Good QC measure for constancy test

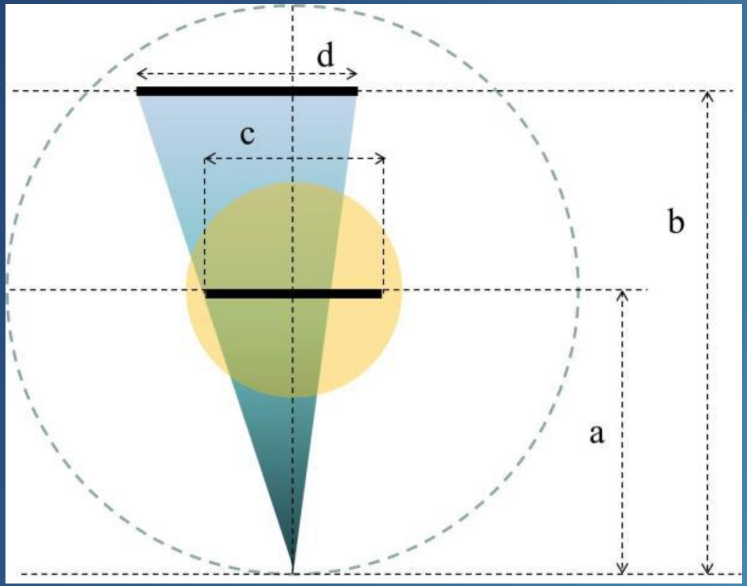
Dose over the diameter of the field of view (D_{FOV})

- For symmetric scanning, ISL correction to isocenter
- For asymmetric “half-beam” geom, d/c < b/a
  - Reflects dose reduction vs full FOV scan
- D_{FOV} useful for
  - Radiation output QC
  - Comparison between systems
  - Required in Germany

$$D_{FOV} = K_A(FDD) \cdot \frac{b}{a} \cdot \frac{d}{c}$$



Symmetric scan geom



Asymmetric scan geom

Dosimetry recommendations by various expert groups

- NCRP 177 “Radiation Protection in Dentistry and Oral & Maxillofacial Imaging” (2019)
  - Focused exclusively on effective dose reports from the literature
  - Did not discuss or take a position on how to measure dose
  - Mentions that effective dose estimates in the literature based on KAP and conversion coefficients, but acknowledged large uncertainties because of variation in scan volume and anatomy

www.ncrponline.org

Dosimetry recommendations by various expert groups: EFOMP/ESTRO/IAEA


E F M P

European Federation of Organisations for Medical Physics

ESTRO European Society for Radiotherapy & Oncology

IAEA International Atomic Energy Agency

Quality control in cone-beam computed tomography (CBCT)

EFOMP-ESTRO-IAEA protocol

Final version 2nd of June 2017

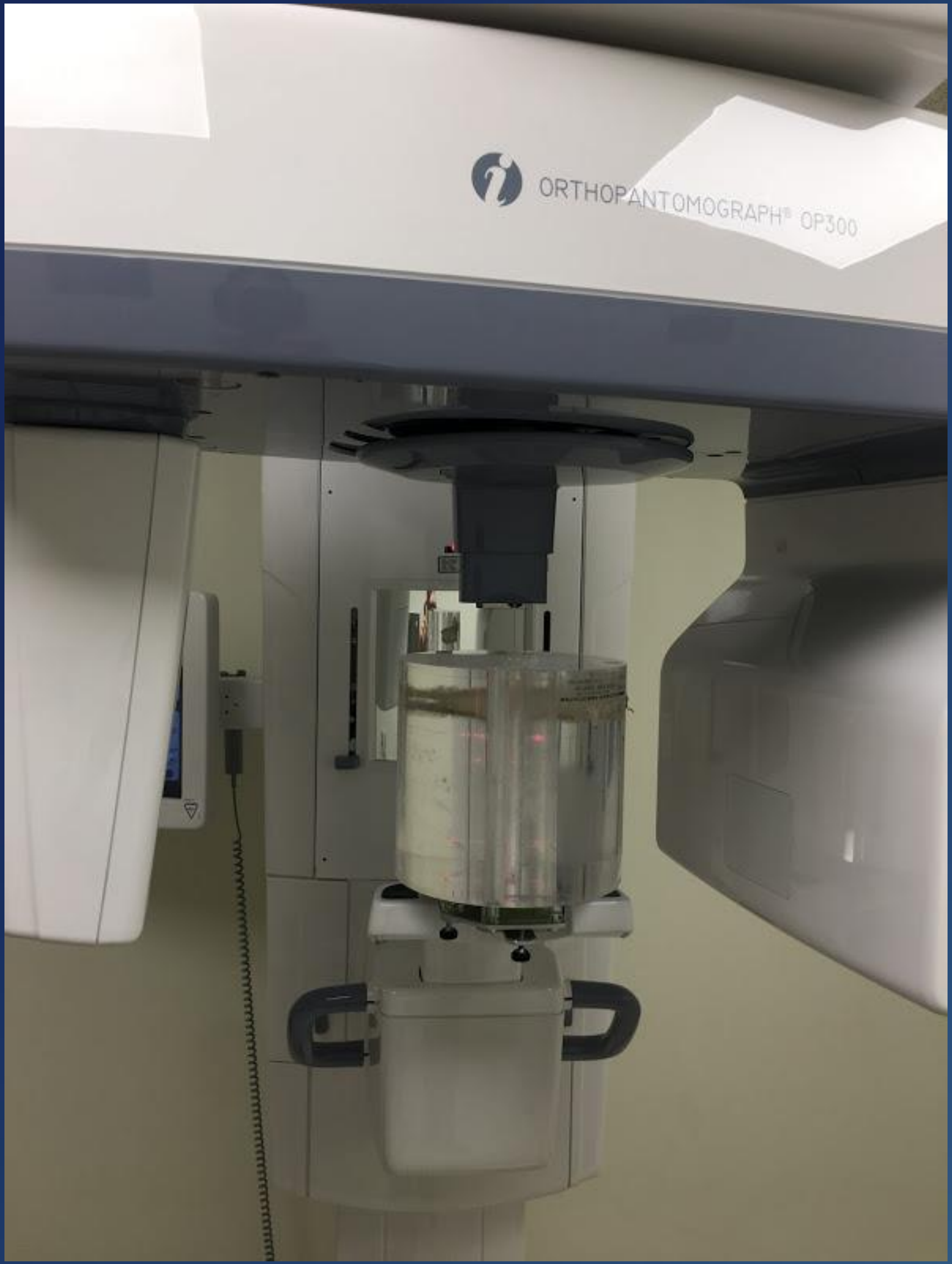
- EFOMP/ESTRO/IAEA “Quality control in CBCT”
- Tests of Radiation Output
  - “Due to lack of standardization of radiation dosimetry for general CBCT applications …”
  - KAP
    - Required for DRL/AD in UK
    - Complete assessment of radiation beam and reliable measure for QC
  - AK at the focus-to-detector distance K_a(FDD) or D_{FOV}
    - Required to be reported in Germany
    - Reliable measure for QC and most convenient of all measurements
  - Dose in phantom (CTDI, CBDI, TG111, etc)
    - Convenient for comparison with MDCT dose
  - All have “advantages” for CBCT QC, but “insufficient … for applied patient radiation dosimetry”

https://www.efomp.org/uploads/2017-06-02-CBCT_EFOMP-ESTRO-IAEA_protocol.pdf

Dosimetry recommendations by various expert groups: EFOMP/ESTRO/IAEA

- In-phantom dosimetry problems
  - Phantoms are too small to represent primary + scatter
  - Positioning phantoms can be difficult on dental CBCT units
- KAP and K_a(FDD) are free-in-air
  - No patient phantom, so no patient dose info
  - But good for QC

https://www.efomp.org/uploads/2017-06-02-CBCT_EFOMP-ESTRO-IAEA_protocol.pdf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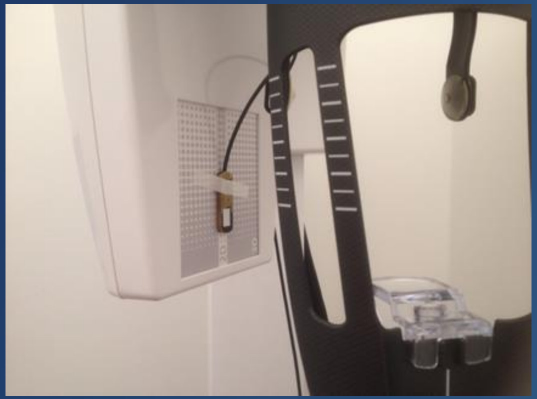
Dosimetry recommendations by various expert groups: EFOMP/ESTRO/IAEA


E
F
M
P
EFOMP
European Federation of Organisations for Medical Physics
ESTRO
European Society for RADIOTHERAPY & ONCOLOGY
IAEA
International Atomic Energy Agency
Quality control in cone-beam computed tomography (CBCT)
EFOMP-ESTRO-IAEA protocol
EFOMP
Final version 2nd of June 2017

KAP measurement



K_a(FDD) measurement

https://www.efomp.org/uploads/2017-06-02-CBCT_EFOMP-ESTRO-IAEA_protocol.pdf

AAPM TG261 dosimetry recommendations (PRELIMINARY)

- $CTDI_w$
  - Sometimes called "CTDI-like" when used in wide beam conditions
  - Use traditional CTDI formula – normalized by nominal beam width
  - Alternatively, normalize by min{L,100 mm}   ("CBDI")
- DAP/KAP
  - Reported by most dental CBCT units
  - Can be measured in the clinic with appropriate instrumentation
- Air kerma at the detector entrance surface
  - Easiest dose metric to measure in the clinic
  - Allows simple conversion to D_{FOV}

Conclusions

- Dosimetry of dental CBCT is not standardized
  - Several options exist
    - Some advantageous for QC {KAP/DAP, K_a(FDD)}
    - Others advantageous for estimating patient dose {CTDI, CBDI}
    - Each has disadvantages
  - Forthcoming AAPM TG261 report will provide up-to-date guidance