Dose Considerations for OnSight 3D Extremity System

Authors: *J. Yorkston, K. Töepfer*

As advanced medical imaging technology becomes more widely available, it is becoming ever more important for medical professionals and patients to understand the relative balance between the risks and benefits of any imaging procedure involving X-rays. This paper will describe the X-ray exposure levels associated with an imaging scan performed on the CARESTREAM OnSight 3D Extremity System and will provide some relative context for these exposure levels in comparison to other sources of X-ray exposure commonly experienced by the public at large.

Any medical X-ray imaging procedure has many different aspects that must be understood to make an accurate assessment of the biological impact caused by the X-ray exposure associated with the procedure. These range from a measurement of the amount (and "quality") of radiation being delivered to the patient and details of the radiation sensitivity of the anatomy being exposed, to considerations of patient set-up within the imaging equipment that affect the amount of the patient anatomy that is exposed to the radiation. Each of these topics will be discussed below.

The CARESTREAM OnSight 3D Extremity System is a Cone Beam Computed Tomography system (CBCT) that provides highly accurate 3-dimensional X-ray images of a patient's anatomy. A traditional Multi-Detector CT (MDCT) system images a narrow section of the patient's anatomy, one slice at a time, and requires multiple rotations around the patient to create an image of an extended length of anatomy. In contrast, a CBCT system images an extended length of the patient at one time and requires only a partial rotation around the patient.

Table 1 presents characteristic X-ray output data measured from the OnSight system with a methodology that accounts for the intrinsic differences between MDCT and CBCT systems (including the unique 3-source configuration of the OnSight system). Details of this measurement of Average $CTDI_w$ are beyond the scope of this paper but the information in Table 1 allows a medical physicist to calculate the X-ray output of an OnSight system for any given exposure technique (combination of kVp and mA setting).

	mA			
kVp	**3mA**	**5 mA**	**7 mA**	**9 mA**
70	1.39 mGy	2.32 mGy	3.24 mGy	4.17 mGy
80	2.25 mGy	3.75 mGy	5.25 mGy	6.75 mGy
90	3.06 mGy	5.10 mGy	7.14 mGy	9.18 mGy

Table 1: Calculated Average $CTDI_w$ (mGy) for a range of kVp and mA settings (16cm CTDI phantom)

Measurements of the machine output exposure (such as $CTDI_w$) do not take into account other aspects of patient anatomy and positioning that can significantly alter the determination of the biological effect of the incident radiation. This is readily illustrated by the example of an MDCT scan of a patient's foot/ankle. Different imaging protocols position either a single foot or both feet within the imaging volume. In both studies, the system X-ray output (i.e. the $CTDI_w$) will be the same (assuming the same acquisition technique), but the absorbed dose associated with the study that images both feet will be approximately twice that of a study imaging a single foot. The OnSight system is designed to image only the specific anatomy of clinical interest, and as such, intrinsically exposes less of the patient's anatomy to the X-ray irradiation field than comparable studies on traditional MDCT systems.

To more accurately measure the biological significance of exposure to X-rays, the International Commission on Radiological Protection (ICRP) has defined EFFECTIVE DOSE as the metric for evaluation of the biological impact of exposure to ionizing radiation [(1)]. An Effective Dose calculation incorporates the X-ray energy absorbed by different types of biological tissue, the fraction of the patient's anatomy that is being imaged and the specific radiation-sensitivities of those tissues. This measure better reflects the significance of the biological impact of the radiation used for the given imaging study.

Calculations for the Effective Dose associated with the different scan configurations from the OnSight system listed in Table 1 are in the range ~5 to 40 µSv [2]. The Effective Dose level changes depending on the specific anatomy being scanned, the volume of anatomy being scanned, and the system settings used to acquire the volumetric image. The OnSight system allows the user the ability to optimize these acquisition settings to match their institution's image quality versus patient dose preferences.

To appreciate the significance of this level of X-ray exposure, it is illustrative to compare it to other sources of commonly encountered radiation exposure. Table 2 lists equivalent measures of radiation exposure from a range of commonly encountered medical and natural sources.

Chest MDCT	~7000 µSv [3,4]
Head MDCT	~2000 µSv [3]
Extremity MDCT	~30 to 160 µSv depending on anatomy and study details [6]
Chest radiograph	~20 to 100 µSv depending on study details [3]
OnSight CBCT Extremity scan	~5 to 40 µSv depending on anatomy and study details
2D Radiographic study of an extremity	~0.2 to 3 µSv depending on anatomy and study details [5]
1 day natural background exposure	~17 µSv [3]
1 trans-continental flight from NY to LA	~25 µSv [7]

Table 2: Comparison of Effective Dose for a range of commonly encountered sources of medical and natural radiation exposure

One final aspect of radiation exposure that is important to consider is the contribution of peripheral absorption of scattered radiation. This underappreciated aspect of additional patient exposure results from the scattered radiation generated by the interaction of the primary X-ray beam with the patient's anatomy. This mechanism delivers X-ray exposure to regions outside the volume of the patient being imaged. The OnSight system was configured to have a geometry that is tailored to the range of anatomy that it is designed to image. This geometric configuration, coupled with the internal lead shielding and the scatter shielding lead curtains that protect the patient, ensure that this additional source of X-ray exposure is minimized compared to traditional MDCT.

In conclusion, through a combination of numerous design features, the CARESTREAM OnSight 3D Extremity System provides clinicians with exceptional quality volumetric images of a patient's extremities at a radiation exposure level that is less than traditional volumetric imaging technologies and "low" compared to other natural sources of radiation exposure.

Weight-bearing ankle exam using the CARESTREAM OnSight 3D Extremity System

References:

(1) ICRP 2007 Recommendations of the International Commission on Radiological Protection *ICRP Publication 103; Ann. ICRP* ***37*** (2-4)

(2) Calculations performed using PCXMC V2.0 (STUK:Radiation and Nuclear Safety Authority Finland) after the approach of Saltybaeva et.al. *"Estimates of Effective Dose for CT Scans of the Lower Extremities"* Radiology (2014) 273(1):153-8.

(3) www.epa.gov/radiation/radiation-sources-and-doses

(4) McCollough et.al. *"Answers to common questions about the use and safety of CT scans."* Mayo Clin Proc. (2015) 90(10):1380-92

(5) Huda W. et.al. *"Radiation Dosimetry for Extremity Radiographs"* Health Physics (1998) 75(5):492-499

(6) Biswas et.al. *"Radiation Exposure from Musculoskeletal Computerized Tomographic Scans"* J. Bone Joint Surg. Am. (2009) 91:1882-9

(7) http://jag.cami.jccbi.gov/cariprofile.asp

John Yorkston is a senior scientist in Carestream Health's Research and Innovation Laboratories. He has extensive experience with flat panel x-ray detectors and their clinical application. He was the lead scientist in the development of the OnSight system and continues to research orthopeadic and radiographic advanced clinical applications enabled by the high-quality images provided by the OnSight system.

Karin Töpfer is an Imaging Physicist in Carestream's Research and Innovation Laboratories. She is an expert in medical image quality and performance modeling of digital X-ray detectors. In addition, she designs robust operating cycles and image calibrations and corrections for portable digital X-ray detectors.