SSA19

ISP: Physics (Computed Tomography I: New Techniques/Systems)

Scientific Papers

PH CT

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Participants

Moderator
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Moderator
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Sub-Events

SSA19-01

Physics Keynote Speaker: State of the Art, Recent Advances and Applications of CT

Willi A. Kalender PhD (Presenter): Consultant, Siemens AG Consultant, Bayer AG Founder, CT Imaging GmbH Scientific Advisor, CT Imaging GmbH CEO, CT Imaging GmbH

SSA19-03

High Performance Cone Beam CT Imaging of Acute Traumatic Brain Injury

Alejandro Sisniega PhD (Presenter): Research Grant, Carestream Health, Inc , Wojciech Zbijewski PhD : Research Grant, Carestream Health, Inc , Hao Dang : Research Grant, Carestream Health, Inc , Jennifer Xu : Research Grant, Carestream Health, Inc , Joseph Webster Stayman PhD : Research Grant, Varian Medical Systems, Inc , John Yorkston PhD : Employee, Carestream Health, Inc , Nafi Aygun MD : Nothing to Disclose , Vassiliss Koliatsos MD : Nothing to Disclose , Jeffrey H. Siewerdsen PhD : Research Grant, Siemens AG Consultant, Siemens AG Research Grant, Carestream Health, Inc Royalties, Elekta AB

PURPOSE

CT is sensitive to the detection of fresh blood in the brain (30-50 HU contrast) and is a front line modality for diagnosis of traumatic brain injury (TBI). Benefit to early detection of TBI would be gained from imaging at the point-of-care immediately following suspected injury. We report dedicated cone-beam CT (CBCT) system with image quality sufficient for detection of mild-moderate TBI (e.g., 1-4 mm fresh blood) suitable to point-of-care deployment.

METHOD AND MATERIALS

CBCT image quality requires novel system design, high-quality reconstruction, and high-fidelity artifact correction, including x-ray scatter, image lag, veiling glare, and beam hardening. Scatter correction uses a fast Monte Carlo (MC) simulator combining GPU parallelization, variance reduction, and denoising to provide corrections in less than 5 min. Detector lag is corrected by deconvolution with a measured temporal response function. Off-focal radiation and veiling glare are mitigated by deconvolution with the long tails of the detector point spread function. Beam hardening is compensated using the Joseph-Spital approach. The framework was tested on CBCT data of a head phantom including simulated brain and hemorrhages (~40 HU) ranging 2-10 mm diameter. The system design included a flat-panel detector with source-axis and source-detector distance of 58 and 80 cm, respectively, and acquisition protocol 100 kVp, 285 mAs (13.4 mGy).

RESULTS

Uncorrected CBCT data exhibited non-uniformity (NU) of 165 HU and contrast-to-noise ratio (CNR) of 1.38 (blood-to-brain) with numerous major artifacts. Scatter correction improved the uniformity to NU = 48 HU and increased CNR by 84%. Lag and off-focal glare correction improved uniformity (NU = 46 HU) without increase in noise (CNR = 2.42). Beam hardening correction further improved non-uniformity to 10 HU, particularly at the skull base and peridural periphery. PL reconstruction reduced noise compared to FBP without loss in resolution, yielding CNR = 2.81.

CONCLUSION

Multi-component artifact correction was essential to achieving CBCT image quality suitable to low-contrast soft-tissue imaging of the brain. Initial results support the development of a novel system for point-of-care TBI detection.

CLINICAL RELEVANCE/APPLICATION

Advanced CBCT artifacts correction techniques allow detection of subtle microhemorrhages in the brain, enabling point-of-care imaging of mild-moderate traumatic brain injury.

SSA19-04

Implementation of an Open Data Format for CT Projection Data

Xinhui Duan PhD (Presenter): Nothing to Disclose , Cynthia H. McCollough PhD : Research Grant, Siemens AG

PURPOSE

Lack of access to projection data from patient CT scans is a major limitation for development and validation of new reconstruction algorithms for dose reduction. To meet this critical need, we are developing a freely-available library of reference patient data sets, which will include image and projection data. To accomplish, we sought to develop and validate a standardized, vendor-neutral format for CT projection data, which will be used in our reference patient library.

METHOD AND MATERIALS

The framework for the projection data format was developed by Battelle Memorial Institute as a proposed extension to current DICOM standards. In this framework, five groups of newly-defined Information Object Definitions were included as DICOM tags, containing essential information about data acquisition necessary for image reconstruction. For this work, only a subset of these tags was needed. Projection data were stored as binary data in a pre-defined order and format. To validate the implementation, CT projection data were acquired from two CT scanners (Siemens Definition Flash and GE Discovery 750HD), where the ACR phantom was scanned in axial and helical modes. After decoding (by us for Siemens, by the manufacturer for GE), the projection data were converted to the DICOM format. An off-line CT reconstruction was performed using only the information stored in the converted data file.

RESULTS

The converted projection data files are compatible with current DICOM standards, so the projection data can be directly viewed using existing DICOM software. The reconstructed images were similar in spatial resolution compared with the manufacturer's reconstruction, even though different reconstruction approaches were used. This confirms that the geometric parameters used in the reconstruction were accurate and the data were correctly stored and retrieved.

CONCLUSION

A standardized format for CT projection data was implemented for use in a reference patient data library for algorithm development and evaluation.

CLINICAL RELEVANCE/APPLICATION

The successful implementation of an open format of projection data will allow algorithm development and realistic evaluation of dose reduction in CT.

SSA19-05

First Measurements of Projection DQE on Photon Counting Silicon-based Spectral CT System

Moa Yveborg MSc (Presenter): Stockholder, Prismatic Sensors , Cheng Xu : Nothing to Disclose , Mats Persson : Nothing to Disclose , Staffan Karlsson : Nothing to Disclose , Hans Bornefalk MS : Nothing to Disclose , Han Chen : Nothing to Disclose , Ben Huber : Nothing to Disclose , Xuejin Liu : Nothing to Disclose , Mats Danielsson PhD : Stockholder, Prismatic Sensors AB President, Prismatic Sensors AB Stockholder, Innovicum AB President, Innovicum AB Research Grant, Koninklijke Philips NV Stockholder, Biovica International AB Board Member, Biovica International AB

PURPOSE

Indicative research have shown electronic noise to be a limiting factor in low-dose clinical computed tomography (CT) using energy integrating x-ray detectors. We are developing a photon-counting silicon detector with 8 energy bins and 0.2x0.3 mm^2 detector elements at the isocenter for clinical CT applications. The purpose of this work is to measure the detective quantum efficiency (DQE) in the projection domain of our silicon detector when mounted in a Philips iCT gantry and show that the electronic noise has little impact on the measured signal.

METHOD AND MATERIALS

The detector module consists of a diode array on a silicon substrate with a thickness of 0.5 mm. One module contains 50 strips constituting the detector elements, each with a cross-section of 0.2x0.3 mm^2 at the isocenter transverse to the beam direction. For this work, we have tested the first modules of a full photon counting CT system mounted in a Philips iCT gantry. We measure the pre-sampled MTF of the silicon detector at by scanning a single pixel using a narrow slit source of x-rays and taking the Fourier transform of the resulting profile. The noise power spectrum (NPS) and DQE are calculated from measurements at several clinically relevant input count rates. We use GATE (Geant4 Application for Emission Tomography) to simulate the photon interaction in a model of the silicon detector and compare the results to corresponding physical measurements.

RESULTS

The results of the measurements demonstrate the electronic noise to have little impact on the measured signal. The simulation model is validated using physical measurements and the estimated DQE of the final detector configuration presented.

CONCLUSION

The first modules of a full photon counting CT photon-counting silicon detector with eight energy bins has successfully been mounted and tested in a Philips iCT gantry. Measurements of the MTF, NPS and DQE is presented, demonstrating a dose-reduction potential in low-dose clinical CT applications compared to conventional energy integrating detectors.

CLINICAL RELEVANCE/APPLICATION

A typical application is low dose CT imaging, such as lung cancer screening and pediatric imaging.

SSA19-06

3D Imaging of the Foot and Ankle Using a Dedicated Extremity Cone-Beam CT Scanner

Gaurav Kumar Thawait MD (Presenter): Nothing to Disclose , Lew Schon MD : Royalties, DJO, LLC Royalties, Arthrex, Inc Royalties, DARCO International, Inc Royalties, Gerson Lehrman Group, Inc Royalties, Zimmer Holdings, Inc Royalties, Reed Elsevier Speakers Bureau, Tornier, Inc Speakers Bureau, Biomet, Inc Speakers Bureau, Zimmer Holdings, Inc Speakers Bureau, BioMimetic Therapeutics, Inc Consultant, Biomet, Inc Consultant, BioMimetic Therapeutics, Inc Consultant, Guidepoint Global, LLC Consultant, Gerson Lehrman Group, Inc Consultant, Tornier, Inc Consultant, Wright Medical Technology, Inc Consultant, Zimmer Holdings, Inc Consultant, Royer Medical, Inc Consultant, Carestream Health, Inc Stockholder, Tornier, Inc Stockholder, Royer Medical, Inc Stockholder, Bioactive Surgical, Inc Stockholder, HealthpointCapital Research support, Royer Medical, Inc Research support, Zimmer Holdings, Inc Research support, Tornier, Inc Research support, Arthrex, Inc Research support, SpineSmith LP Research support, Biomet, Inc Research support, BioMimetic Therapeutics, Inc Support, Bioactive Surgical, Inc Support, Educational Concepts in Medicine, LLC Support, Smith & Nephew plc Support, OrthoHelix Surgical Designs, Inc Support, Chesapeake Surgical Biocomposites Support, Olympus Corporation Support, Omega Surgical , Grace Jianan Gang : Nothing to Disclose , Wojciech Zbijewski PhD : Research Grant, Carestream Health, Inc , John Yorkston PhD : Employee, Carestream Health, Inc , John A. Carrino MD, MPH : Consultant, BioClinica, Inc Consultant, Pfizer Inc Advisory Board, General Electric Company , Jeffrey H. Siewerdsen PhD : Research Grant, Siemens AG Consultant, Siemens AG Research Grant, Carestream Health, Inc Royalties, Elekta AB , Shadpour Demehri MD : Nothing to Disclose

PURPOSE

A prototype cone-beam CT (CBCT) scanner has been developed with capability for imaging of the weight-bearing (or non-weight-bearing) lower extremities. This work reports the first investigation of image quality and dose in relation to imaging of the foot and ankle.

METHOD AND MATERIALS

The technical performance of the new clinical CBCT scanner was assessed in terms of spatial resolution, soft-tissue contrast resolution, and radiation dose. Clinical performance in imaging of the foot and ankle was assessed in a prospective IRB-approved study of 11 patients (8 female, 3 male; 32-62 yo, mean 43 yo) with ankle pathologies including fracture, tendonitis, osteoarthritis, and rheumatoid arthritis. Image quality was evaluated by a musculoskeletal radiologist and orthopedic surgeon in visualization tasks pertinent to each pathology. Patients with foot and/or ankle fracture were imaged longitudinally to characterize fracture healing, detect non-union, and quantify bone remodeling patterns in high-resolution 3D images.

RESULTS

The scanner exhibited spatial resolution of ~15-17 lp/cm (~0.5 mm) and contrast resolution sufficient for visualization of cartilage, ligament, tendons, and muscles. Radiation dose was less than that measured in conventional multi-detector CT protocols (CTDIw = 9 mGy, SSDE = 13 mGy for an 8 cm diameter ankle, compared to 25 mGy, SSDE = 35 mGy). The images provided clear visualization of numerous pathologies in the foot and ankle, including cartilage loss, soft tissue edema, bone cysts, erosions, subtle fractures, and non-union. The high spatial resolution enabled quantification of fracture healing patterns, including bridging trabeculae and cortical remodeling.

CONCLUSION

The prototype scanner exhibited spatial and contrast resolution sufficient for a broad range of diagnostic imaging tasks in the foot and ankle. The capability for weight-bearing imaging could offer a valuable tool for diagnosis and treatment assessment in various ankle pathologies including flat foot, osteoarthritis, and fracture nonunion.

CLINICAL RELEVANCE/APPLICATION

CBCT of the foot and ankle can provide functional information and precise morphological analysis in cross sectional imaging not achieved by radiographs.

SSA19-07

Taking Grating-based X-ray Phase Contrast Imaging to Clinically Relevant X-ray Energies

Adrian Sarapata MSc (Presenter): Nothing to Disclose , Michael Chabior : Nothing to Disclose , Dan Stutman PhD : Nothing to Disclose , Franz Pfeiffer : Nothing to Disclose

PURPOSE

Grating based X-ray phase contrast imaging can work with conventional X-ray tubes and provides complementary information about the specimen. The technique has been proven to provide higher soft tissue contrast in comparison to conventional attenuation-based imaging. The essential next step is to get the X-ray energy up to clinically relevant levels. Our goals are to open possibilities for imaging of thick human body parts with bones as well as reduce the radiation dose.

METHOD AND MATERIALS

A Talbot-Lau grating interferometer with 3 gratings was used at the designed energy of 45 keV. X-ray photons were generated by an X-ray tube with a molybdenum target operated at 75 kVp. Grating structures of an absorption grating had 150 micrometers in height. The system was operated at the normal incidence angle of the gratings. Several biological samples were measured to demonstrate the capabilities of the system; among others, a 4.5 mm thick sample submerged in 8 cm thick water bath. The soft tissue contrast and image quality of CT scan images were compared with soft tissue phantom results obtained with a glancing-angle grating interferometer, which have been published elsewhere.

RESULTS

The CT scans show improved soft tissue contrast in comparison with the absorption based images. At this Compton effect-dominated energy range the phase contrast images are still superior to the absorption based images. But a system with high fringe visibility and high angular sensitivity should be considered for clinical applications, because of the biggest difference in soft tissue contrast between phase contrast and absorption based images.

CONCLUSION

Grating-based X-ray phase contrast imaging can be successfully used with an X-ray spectrum of 45 keV mean energy. Phase contrast images provide higher soft tissue contrast than absorption based images, even from a not perfectly optimized system. This shows huge potential of high energy grating-based X-ray phase contrast imaging for clinical applications.

CLINICAL RELEVANCE/APPLICATION

The study represents an important step towards clinical implementation of grating-based X-ray phase contrast imaging, as it demonstrates the possibility of the technique to be used at clinically relevant X-ray energies.

SSA19-08

The Feasibility of 2D Fluence Field Modulated CT Using Attenuating Filters

Timothy Peter Szczykutowicz PhD (Presenter): Equipment support, General Electric Company Research Grant, Siemens AG , Charles Anthony Mistretta PhD : Founder, Mistretta Medical Intellectual Property Licensing Activities Research, Siemens AG

PURPOSE

The purpose of this study is to compare the gains in tissue compensation and dose reduction possible when using a 2D fluence field modulator compared to a 1D modulator and bowtie filtration.

METHOD AND MATERIALS

A 2D fluence field modulator was simulated assuming two continuous 1D modulators could be placed orthogonal to each other. This produces an additively separable 2D fluence field. A 1D modulator was also simulated. Two different size bowtie filters were also simulated, one optimized for the head, and one optimized for the body. Comparisons were made for chest, thorax, abdomen, pelvis, and head anatomical regions. The ability to compensate for tissue was quantified by calculating the standard deviation of the sum of the attenuation from the patient anatomy and the 2D/1D modulator or bowtie. Dose comparisons were made by first setting the mA such that peak variance was minimized. The x-ray fluence incident onto the anatomy was summed and used to make relative dose comparisons between the various modulators. Lastly, a piecewise constant modulator was simulated for the 2D modulator using realistic numbers of wedges as have been previously experimentally implemented.

RESULTS

As expected, in terms of dose reduction and tissue compensation, the best modulation design was 2D, followed by 1D, and then bowtie filter respectively. The largest benefit from 2D modulation relative to 1D modulation was in the thorax, the smallest in the head. On average, the 2D modulated allowed for a dose reduction of 3.7 and 21 times relative to 1D and bowtie filter modulation respectively. The average increase in tissue compensation for 2D modulation was 1.2 and 3.25 times relative to 1D and bowtie modulation respectively.

CONCLUSION

2D modulation does provide large advantages over 1D tissue compensation and would likely benefit FFMCT, especially wide cone angle CT like that found on c-arm and some MDCT systems. Large dose reduction are possible when peak variance is minimized instead of average variance. 2D modulation allows for large dose reductions for large cone angle systems as z-axis dose modulation is not possible with traditional bowtie filtration/mA modulation methods for these systems.

CLINICAL RELEVANCE/APPLICATION

Fluence field modulated CT (FFMCT) allows for another stride along the path of patient specific imaging dose tailoring to be realized; switching from 1D to 2D FFMCT can be done at half the dose.

SSA19-09

Task-Driven Image Acquisition and Reconstruction in Cone-Beam CT for Interventional Guidance

Grace Jianan Gang (Presenter): Nothing to Disclose , Joseph Webster Stayman PhD : Research Grant, Varian

Medical Systems, Inc , Sarah Ouadah : Nothing to Disclose , Tina Ehtiati PhD : Employee, Siemens AG , Jeffrey H. Siewerdsen PhD : Research Grant, Siemens AG Consultant, Siemens AG Research Grant, Carestream Health, Inc Royalties, Elekta AB

PURPOSE

New interventional cone-beam CT systems offer considerable freedom in source-detector positioning in addition to prior knowledge of the patient anatomy and intended imaging task. Such systems offer new opportunities to improve image quality and reduce dose. This work reports an optimization framework that identifies patient- and task-specific imaging protocols that maximize task performance and thereby reduce dose.

METHOD AND MATERIALS

We employ a mathematical model of the imaging chain to compute task-specific detectability index (d') for given patient anatomy as a function of the acquisition protocol (including source, detector, and orbit) and reconstruction method (algorithm and parameters therein). Using detectability index as the objective function, an optimization framework was established to identify protocols best suited for a given task. Tube current, parameterized by a scalar , was optimized via exhaustive search keeping total dose within a predefined constraint; using the optimal , reconstruction parameter [e.g., cutoff frequency (f0) in filtered-backprojection (FBP)] was optimized exhaustively for each view. The source-detector trajectory was optimized using a greedy algorithm that successively finds the next best view (angle/obliquity) for maximum improvement in d'. Task-driven current + kernel modulation was applied to a line pair detection task in an elliptical phantom. Trajectory optimization was performed for an intracranial hemorrhage detection task and compared with a circular orbit. Experiments were performed on an experimental CBCT bench.

RESULTS

At the same total mAs, the line pair pattern was conspicuous for task-driven (current + kernel) modulation case but barely distinguishable in the unmodulated and AEC cases. Task-based trajectories designed for hemorrhage detection successfully avoided highly attenuating rays associated with the embolization coils and skull base, yielding reconstructions with major reduction of noise and artifacts.

CONCLUSION

Compared to conventional acquisition and reconstruction, a task-driven imaging approach tailored to specific patient anatomy and imaging tasks demonstrates the potential for improved image quality and reduced dose.

CLINICAL RELEVANCE/APPLICATION

The task-driven framework synergizes advances in image quality modeling, advanced C-arm systems (e.g., Zeego), and model-based reconstruction to achieve improved image quality and reduced dose.