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CT Clinical Perspective: Challenges and the Impact of Future Technology Developments

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Abstract— **Computed tomography is not the most frequent radiologic imaging procedure, but is arguably the most important in terms of clinical impact. CT is used extensively for emergencies, cardiovascular, pulmonary, gastrointestinal, endocrine, neurological, orthopedic and other applications - often as the first and only imaging procedure needed for diagnosis. The chances are very high that a patient will have a CT scan in the emergency department, as an outpatient or as an inpatient for a multitude of indications - pain, trauma, suspected infection or malignancy, and frequently to investigate symptoms such as pain, or to answer a question raised by another abnormal test, such as an EKG abnormality or ultrasound finding. Despite the universality of CT in hospitals and clinics as well as free-standing imaging centers, the technology continues to evolve with greater coverage, faster acquisition and multienergy sources or detectors. The most demanding imaging applications are cardiovascular, where complex motion and small morphologic features coexist, so imaging methods that are very satisfactory elsewhere in the body may not be successful. Clinical CT scanning consists of administering toxic materials, e.g., contrast media, often monitoring the EKG and illuminating the body with high brightness x-rays. Larger area detectors and higher acquisition rates are welcome improvements, but don't solve all of the problems encountered with scan variability due to respiratory, random body, and cardiac motion, especially in a spectrum of patients from infant to massively obese adult sizes (< 1 kg to 250 kg or more). The challenges and pitfalls in CT will be delineated and evaluated relative to current and future technology.**

I. Introduction

Among the principal challenges in diagnostic medical imaging, especially CT, are the "evidence gap"; concerns with overuse and the economics of medical imaging while the applications for oncology, neuroimaging, cardiovascular, orthopedic are growing. In this paper, we identify major trends – the recent introduction of 256-320 channel CT scanners in comparison with widely used 16- and 64-slice scanners. High end CT scanners are especially useful for neuroimaging, such as whole brain perfusion; cardiac imaging using step-and-shoot acquisition; 4D angiography with whole organ perfusion; non-gated chest CT scanning, and many more. [1,2]

Physicians often seem to prescribe CT and MRI scans when they are of little or no medical use, perhaps explaining why Canadians still face hefty delays to get the tests, a new Ontario study suggests. Large percentages of the scans reviewed by the researchers either unearthed no medical problems, or detected abnormalities that would not change how the patient was treated, raising questions about whether they should have been ordered in the first place. [3]

Medical spending in the United States has continued to soar, reaching an estimated $2.25 trillion in 2007. The nation now spends 50% more on health care per capita than the next closest industrialized country, often with no better outcomes for patients. One reason is overuse of medical technology. The US spends more for healthcare but the results do not justify the cost and the growth in medical expenses is not sustainable. [4]

II. Clinical Computed Tomography

A. Radiation Dose

Image gently is an initiative to minimize the radiation dose from CT, one of the highest among imaging modalities, especially in children. Recommended protocol templates are available in Excel™ spreadsheets for implementation on common clinical CT scanners. Best practices, advocated by pediatric radiology subspecialists, have been disseminated to ensure that the exposure is minimized and examinations are necessary. [5]

Low end CT scanners have been developed for point of care CT scanning in the medical office or ICU [6], DentoMaxilloFacial/ENT CT scanning as an alternative to orthopantographic radiography, while high end CT in the cardiac cath lab (for application to percutaneous intervention - PCI) and interventional suite to complement or supplement fluoroangiography. [7,8]

B. 256-320 row MDCT scanners

Recently, new high end Multirow Detector CT (MDCT) scanners have been introduced with impressive technical specifications. For example, this year we installed a 128 detector rows; 256 slices (iCT) scanner with substantially increased speed, power, and coverage. This instrument can complete a nose to toe scan comprising 168 cm in 22 sec yielding submillimeter isotropic resolution by generating more than 10,000 slices in a single dataset. This scanner was redesigned using several technical innovations (gantry on air and new curved building block detectors) providing higher temporal resolution (0.27 sec per rotation), increased x-ray tube power (120 kW / 1,000 mA), X-Y and Z focal spot modulation, with 2X greater coverage per rotation (8 cm vs 4 cm for 64-channel CT scanners), and 256 slices per rotation. [9,10]

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Several other examination modes are available, which were not possible with predecessor instruments, including a complete multi-phase cardiac Imaging less than 5 sec, non-gated chest CT scans that faithfully depict cardiac and bronchiolar anatomy without artifacts, A non-gated scan of chest can be completed in 4 secs with improved coronary visualization despite non-gating. CT Bronchoscopy with a non-gated scan, isotropic head & neck examination, and very large (BMI > 50) cardiac patients can be a challenge to image, but they are readily performed on the new top end scanners.

C. CT Perfusion – Acute Stroke Imaging

Perfusion imaging produces color coded parametric maps that overlay the routine gray scale scans. Numerous imaging modalities have been applied to cerebral imaging, so there is a continuing debate on which imaging approach is best: CT vs. MRI vs. xenon CT vs. PET vs SPECT. [15]

MRI of cerebral ischemia is an ideal examination for early detection of stroke, combining T1, T2 weighted multiaxial scans. There is greater availability of CT, however, especially for patients who are in the earliest stages of stroke, when thrombolytic therapy is possible, if the diagnosis can be made within the first 3 hours. To do this, there has been a national effort of academic, government agencies (NIH, DOE, FDA), and industry that resulted in formulation of a roadmap for acute stroke imaging, published in 2008. [23] CTA of the neck and circle of Willis has now become the favorite non-invasive tool of many neurosurgeons and neurointerventionalists. The data set can be manipulated to detect small aneurysms or arterial dissections and aid in planning optimal approaches to treatment. [14]

Among the most important aspects, is combination of non-contrast CT (to detect the presence of acute hemorrhage), CT perfusion for stroke detection, and CT angiography to define the cerebral circulation.

Earlier CT scanners were capable of perfusion measurement, but only within a single predefined slice. Whole brain CT perfusion has recently become available with top of the line scanners, especially the 320 slice, 16 cm unit introduced into clinical practice recently. Imaging ischemic brain parenchyma is a particular strength. [16]

The triple rule-out of acute chest pain is a technically demanding type of emergency examination that simultaneously evaluates the aorta for dissection, the pulmonary arteries for embolism, and the coronary arteries for plaque or infarct.

Renal CT Angiography (CTA) benefits from wide area coverage multislice scanners to study renal artery stenosis, trauma, transplant donor, neoplasm. Peripheral CTA
256-slice CT scanner (2009). Another example of Cardiac CTA in a patient with chest pain uses a dual injector with a second diluted bolus of contrast to visualize the right ventricle and pulmonary tree. This approach can reveal acute pulmonary emboli incidentally seen on a cardiac study.

The newest CT scanners with 8-16 cm z-axis coverage are well suited to evaluation of cerebrovascular disease, in stroke (arterial & venous). Whole brain perfusion examination capability available with these instruments is new. Comibned with dynamic whole-head CT angiography with high temporal resolution, bone subtraction – petrous ICA, V4, stents – can be achieved with a single 50 ml IV contrast material bolus injection (compared with 120 ml on earlier generation scanners). The cerebral CTA can be combined with CTA of the supra-aortic vessels. [18]

Most recently, the mechanical components in the CT gantry, which continuously transport the x-ray source, detector array, and high voltage power supply around the patient have been refined to increase temporal resolution to as little as 0.27 sec per rotation. The X-ray generator power was increased to 120 kW, a necessary improvement since the time available to expose a given body part is less as the mechanical components become faster. The x-ray dose does not increase, at least as measured in mAs, since for a constant exposure the current must increase as the time becomes shorter. Coverage has increased for cardiac and large area scanning to between 8 and 16 cm (vs. 4 cm on 64-slice CT). Between 256 and 320 slices are simultaneously acquired. In the 8 cm version of a top end scanner, there is a "Smart" Focal Spot which is non-stationary, allowing denser ray sampling by simultaneously moving the x-ray source and focal spot. Despite the faster gantry apparatus and higher x-ray tube power, these systems typically require lower doses due to a reduced penumbra and other innovations such as a special motorized collimator that limits dose and penumbra. [17,19,20]

After installing a top-of-the-line scanner this year, we performed a comparison of 16, 64, and 256-slice CT scans obtained on the same patients. It is common to examine some patients with CT scanning more than once. In many instances, such as follow-up oncology studies on solid tumors seen only by CT, we have scans obtained on the same patient with these different scanners from the same manufacturer with a interval of less than two or three months. There are some recognizable differences in CT image quality when such a comparison is done.

D. Dual Energy CT

Dual energy CT scanning is not new as a laboratory technique, but its introduction into clinical practice is a recent development. There are basically three ways to obtain dual energy CT scans: 1) Dual source (and detectors) – most expensive, 2) Energy-discriminating detectors – moderately expensive and 3) Energy-switching source – least expensive. [11, 12, 13]

The most complex and expensive of these is Dual Source CT, provided by duplicating the source and detectors. Simultaneous sampling of orthogonal beams is possible, including low and high energy. The Dual Source CT has limited z-axis coverage, but is well suited to cardiac, aortic and runoff angiography.

In general, MDCT requirements include separation between calcification and Iodine in CTA, bone-removal in CTA (Cage Removal, Skull Removal etc.), soft plaque separation, quantitative measurements for bone mineral & bone density assessment, low contrast resolution (soft tissues).

In general, the Spectrum Decomposition Principle is used to reconstructed material specific, equivalent monoenergetic, and beam hardening artefact-free scans using the same CT x ray source with a spectrum of different energies generated at 2 or more accelerating potentials (e.g., 80 and 120 kVp are common).

E. Single Source Dual-Energy MDCT

For many practical applications, SSDE MDCT is attractive, and clinical evaluation of this technology is underway. In general, for dual energy CT scanning, every pixel has 2 HU values – for high & low energy. An experimental scanner was constructed with 64 detector rows in a Philips Brilliance CT Prototype where there are 32 detector rows for low energy and 32 detector rows for high energy. The detectors are built stacked one upon another so the high and low energy detectors are superimposed on one another. This scanner has been tested in some clinical experiments to test automated calcium and bone removal from CT angiograms, production of virtual non-contrast images (e.g., akin to scout images without contrast) from post-contrast scans,

Each dual energy scan creates 3 types of images: high energy, low energy, and composite. Every pixel has 2 HU values – for high & low energy.

F. Microprocessor Development

It is appropriate to ask, "What technologies influence CT scanner development most?" Among the most important enabling technologies are CPU and memory used to acquire the raw projection data and generate images.

The development and advances in CT scanning is highly correlated with the development of microprocessors. New in 2008-9 is the 45 nm processors from Intel (previous were 65, 90 nm). The newest microprocessors are faster and have lower power consumption. Recent microprocessor CPU chips have found application in CT data processing and visualization, including the IBM cell processor (used in Playstation 3, for example), GPU chips (graphics processors used in PCs)

In addition to the computational elements, CT scanners are advanced by the x-ray source and detectors. Carbon Nanotube (CNT) electrodes constructed of single-wall nanotube bundles or multi-wall nanotubes with a diameter range of 10~200 nm can yield a field emission current 1-10 microA. The intended applications are as a microelectrode and point field emission electron source. Future CT scanner x-ray source based on CNTs are in development. Carbon nanotubes have shown promise as x-ray sources in microCT for animal imaging. [21]

G. Cone Beam 3-D Imaging System for Dental/ENT Clinic

3-D volumetric dentomaxillofacial images with true anatomic measurements are possible with 12 bit gray scale on relatively inexpensive instruments that have a modest-sized footprint, fast scan time, and require low x-ray radiation dose for high resolution for all views (using an amorphous silicon flat panel image sensor).

In an effective dose comparison, a cone beam scanner can acquire a 20 second scan requiring only 68 microSv with exposure in "pulsed" mode, where the actual exposure time is about 3.5 seconds for a 20 second scan. For a 10 second scan the exposure is only 34 microSv.

This can be compared with daily background radiation of 8 microSv and panoramic dental x-rays (Average) with 10-15 microSv exposure. A Digital Panoramic radiograph requires between 4.7 – 14.9 microSv In the dental office, a full mouth series requires 150 microSv and the dose associated with a Medical CT scan of these structures typically needs 1200-3300 microSv.

H. Portable CT scanner

An 8-Slice portable CT scanner has been developed as a compact, lightweight, mobile, high speed, battery and line powered multi-slice CT scanner. This scanner has a 25 cm field of view, primarily intended for head and neck imaging. Up to 8 slices per revolution are generated, transmitted through a wireless image transfer system (WITS). Non-contrast head CT scans, CT angiography and CT perfusion have been demonstrated.

Siting of an 8-Slice Portable CT Scanner for example, in an ENT Office / Clinic is much simpler and less expensive due to the low output of the x-ray source resulting in less need, if any, for shielding and radiation protection precautions. Scatter dose is significantly reduced and may vary between scanners up to +/- 10%. Dose numbers are air dose and thus more representative of skin dose but not organ dose. Scatter dose depends on the object being scanned and the kVp setting, and scales linearly with the mAs technique. Absorption of scatter by the patient will reduce external scatter rates.

A typical axial acquisition acquires slices with 1 cm slice thickness with user defined acquisition time of 30-45 seconds. The PC processor can generate 1 slice per second.

I. Medical Imaging Workstations

Medical imaging workstations complement high end CT scanners and provide image post-processing, visualization and analysis tools. These may be implemented as a Thick Client – expensive, with substantial local processing capability or as a Thin Client – small, portable and accessible via networking throughout the clinical enterprise. [22]

These workstations and thin client portals provide 3D/MPR viewing plus comprehensive cardiac analysis, brain perfusion-summary maps, ct angiography applications, stenosis measurement and stent planning, lung nodule assessment, and virtual colonography among others.

Thin Client Solutions have been developed as an alternative to dedicated high performance computer graphics and imaging workstations. There has been a revolution in thin-client solutions as they adding more complex applications and 3D to routine CT viewing. These systems complement PACS workstations and may be integrated into them.

III. CONCLUSION

Diagnostic imaging is subject to overuse with limited evidence for a beneficial effect on outcomes in some applications (e.g., cardiac). Imaging modalities (e.g., CT scanners) are becoming both more and less expensive. Low end scanners are becoming available at the Point of Care and clinical office. High end specialty imaging (e.g., CT in the cath lab) is in development.

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