Digital Tomosynthesis Applications and the NANO-X Solution

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Introduction

Digital Tomosynthesis (DTS) is a well-established technique for producing slice images using x-ray systems. It is a refinement of conventional geometric tomography, which was developed in the 1930's by the Italian radiologist Alessandro Vallebona (1). In conventional geometric tomography, the X-ray tube and image receptor move in synchrony on opposite sides of the patient to produce a plane of structures in sharp focus at the plane containing the fulcrum of the motion; all other structures above and below the fulcrum plane are blurred and thus less visible in the resulting image. DTS, on the other hand, allows an arbitrary number of in-focus planes to be generated retrospectively from a sequence of projection radiographs that are acquired during a single motion of the x-ray tube. From these projection radiographs, specific planes are reconstructed to create new images that provide enhanced quality and specificity. The term tomosynthesis originates from two Greek words: “tomos” for a section or a slice and “synthesis” for a process (2).

DTS overcomes the difficulties of geometric tomography by permitting reconstruction of many slices from multiple low-dose acquisitions of image data. It uses an X-ray source and a digital detector to acquire a set of projection images that are combined to synthesize any coronal plane in the patient (3). Unlike conventional tomography, DTS is not limited to reconstruction of a single plane, but rather can generate an arbitrary number of slice images throughout the entire volume of the patient (4).

In this way, it provides a unique and powerful perspective. It addresses one of the primary weaknesses of conventional single-projection X-ray imaging: the superimposition of tissues and structures on each other, which can obscure abnormal findings (5). Despite some early successful proofs of concept, DTS has only recently become practical as a clinical imaging modality. This technique was successfully implemented in Digital Breast Tomosynthesis (DBT) and is now in wider use for additional clinical applications (6).

Current Situation

Several manufacturers of X-ray equipment, now have commercial DTS. As with the various more classical tomographic systems, these vary in their geometric and motion parameters. As a results, there is a growing number of scientific publications, demonstrating the advantages of DTS imaging of chest, abdomen, breast, head, and neck (7). For example, DTS provides improved visibility of anatomical structures in the chest, such as lungs, airways, sternum and ribs with more accuracy (8).

Yet, as of today, the positioning of this technology in routine imaging workflow is not common. Various barriers, such as price (in their current form, these machines are generally expensive), market and radiologists' education, are considered to form the major obstacles for mass adoption of the technology. These issues, in parallel to the common use of other advanced imaging modalities, have led DTS to find its place only in specific niches.

Tomosynthesis Applications

Digital chest tomosynthesis*

DTS of the chest, is a promising technology which overcomes significant limitations associated with plain chest X-ray and brings some advantages by permitting the reconstruction of various image slices from multiple low-dose acquisitions of image data.
Compared to standard radiography, DTS of the chest has several advantages including improved lesion detection due to a reduction in image noise or composite artefact, better depth localization and contrast resolution (Figure 1). Recent reports have shown that the use DTS as an alternative to conventional chest radiography, leads to considerable improvement in diagnostic content (7).

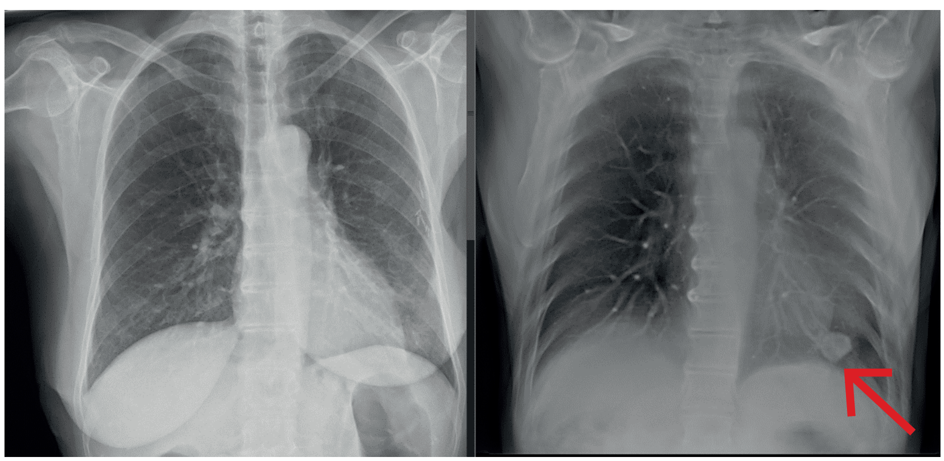

Figure 1^ – Small lesion obscured by anatomy in standard Xray (left) and noticeable in DTS obtained using Nanox.ARC (right).

As mentioned, DTS is emerging as a promising technology for the diagnosis of equivocal or suspected pulmonary lesions (16).
The use of DTS would entail less waiting time for the workup of the suspected lung lesion that then turns out to be benign, non-pulmonary, or a false positive nodule. Prospectively, DTS could replace the CT scan in the characterization of incidental chest lesions identified by conventional radiography (17). Chest DTS highlights the potential to follow up known nodules (18). It also has applications in cystic fibrosis (19) tuberculosis (20) and asbestos-related diseases (21).

Orthopaedic and Rheumatological Imaging

Fractures

The adult human skeleton is made up of 206 bones (270 at birth). These include the bones of the skull, spine (vertebrae), ribs, arms and legs. Fractures are incredibly common and in fact, globally, the person-yearly fracture incidence rate is 1.2% (24,25). In the US alone, 2 million fractures occur each year, including those related to osteoporosis. Many radiologists, especially those in Emergency Departments and Urgent Care settings agree that missing a fracture on 2D X-ray is the most common misdiagnosis accounting for approximately 80% of missed diagnoses (25,26).

DTS therefore can offer significant improvement over X-ray diagnosis, either as an additional tool or as a routine for fracture diagnosis (Figure 2). Due to its innate advantages over 2D X-ray, DTS has been described in the literature as offering improved detection of not only routine fractures but also of micro and occult bone fractures, which can typically be detected only by CT or MRI (27). This modality has been noted to be especially useful in delineating certain complex anatomical structures, including skull, TMJs, facial bones, atlanto-axial joints and carpal and tarsal bones (28)

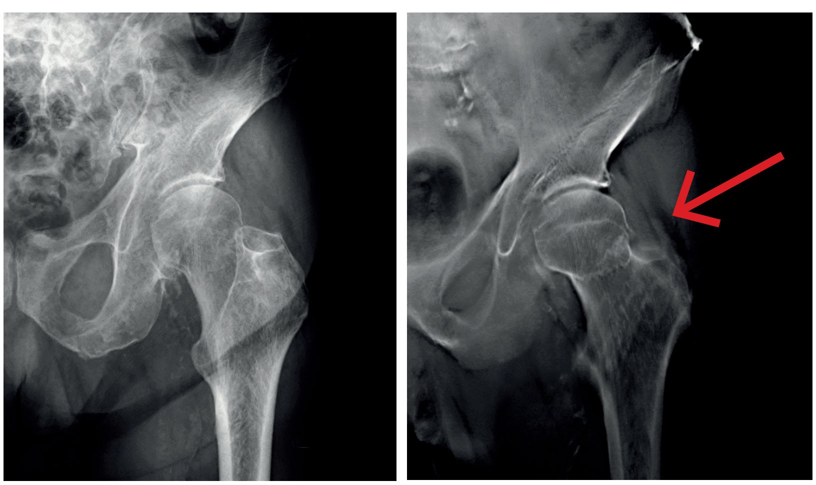

Fig 2^^ An osteoporotic femoral neck fracture in an elderly patient is barely seen on the radiograph (left). The greater trochanter is superimposed on the neck due to the internally rotated hip. The fracture is clearly seen on the DTS despite a similar internal rotation (right). There is a cortical breakthrough and a sclerotic fracture line along the neck.

Joint imaging in Rheumatology

The most utilized imaging modality for evaluation of bones and joints is plain radiography. However, this is also the least sensitive technique for abnormalities compared to CT and MRI. CT of bones and joints is a significant burden on the radiologists since these studies contain hundreds of images and is an expensive and not always readily available tool. MRI, while an unmatched modality for the demonstration of soft tissues, including ligaments, menisci and tendons, has significant limitations in the evaluation of the bone itself. DTS is a good solution for addressing these limitations. (7)

A useful application for arthropathies has also been demonstrated, with outstanding imaging of joint spaces and erosions, suggesting it may become an important element in screening and monitoring of arthropathies (28-30). Several studies have noted that DTS can improve the detection of degenerative and inflammatory arthritis including subtle findings such as erosions. Further studies are needed but it would seem likely that DTS may become the modality of choice for the evaluation of various common conditions in this category including osteoarthritis, rheumatoid arthritis and gout (28-30).

Spine Imaging

DTS of the thoracic spine appears to be a promising alternative to DR, especially in areas where the problem of overlaying anatomy is accentuated, such as posterior and upper thoracic structures (33). In a study performed in the elderly it was shown that DTS significantly increased the detection rate of thoracic fractures when compared with radiography with low added radiation dose (34). Moreover, DTS was found to be a potential technique for measuring the thickness of vertebral endplate and shell which contribute to the overall strength of the vertebral body, are at highest risk of initial failure, and are involved in degenerative disease of the spine (35).

Head & Neck

According to the National Ambulatory Medical Care Survey the prevalence of sinus disease is estimated to be approximately 14% in the general adult population and DTS has already been used with success for accurate detection of sinus disease. Studies have shown that DTS is useful in delineation of complex anatomic structures (7). X-ray evaluation of these structures is usually limited and DTS can contribute to diagnosis of TMJ dislocations, orbital fractures, etc.

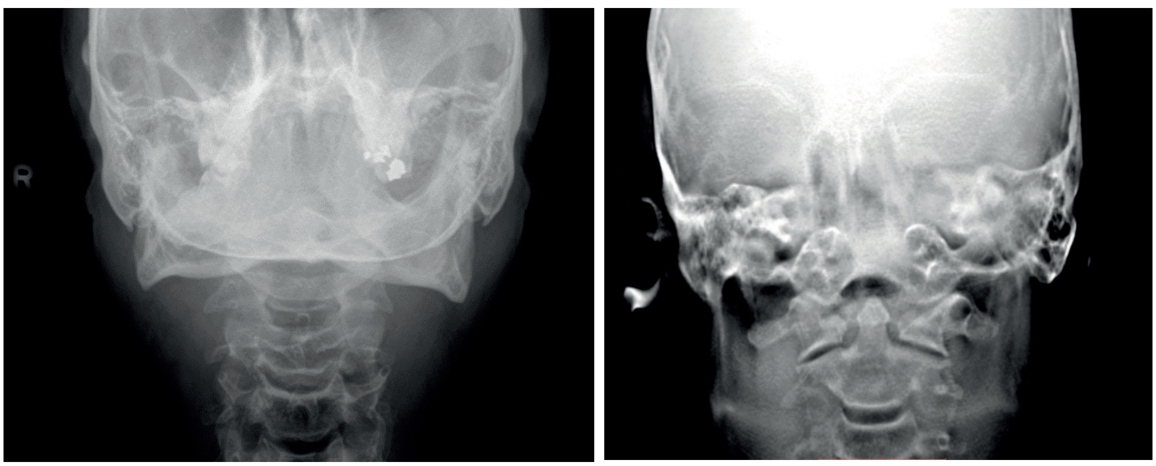

Fig 3 AP radiograph of the cervical spine. The odontoid process and C1-2 articulations are clearly visualized on Nanox.ARC scan (right). They are completely obscured by the skull on conventional radiographs (left).

Abdominal Imaging

DTS abdominal imaging has been demonstrated to be remarkably successful in aiding in the diagnosis of urinary tract calculus disease (31-32). In fact, studies have demonstrated that DTS improves the detection of and location of urinary calculi when compared to digital radiography with only a minimal increase in patient effective radiation exposure dose.

Additionally, it has been shown that DTS abdominal imaging demonstrated improved evaluation of various other abdominal anatomical structures, such as pancreato-biliary, and gastrointestinal tracts. Specifically, it has been demonstrated to improve evaluation of these organ systems when the patient has significant superimposition of bowel gas, and these are notoriously difficult to assess without contrast and/or associated with invasive procedures, and in the evaluation of tumours of the biliary tract in percutaneous transhepatic cholangiography examinations (7).

The Nano-X solution

The vast majority of imaging is X-ray based (X-ray, CT, fluoroscopy**, mammography** etc.). Nano-X has embedded its unique digital X-ray source in its multiple-source Nanox.ARC DTS device. This new technology will not only enable the manufacturing of a DTS device more readily and inexpensively but also aims to form the basis of a novel ecosystem based on source and device, with a unique business model and cloud-based platform. Therefore, Nano-X has the potential to make a significant global impact.

In addition, Nano-X integrates the concept of MSaaS (Medical-Scanning as a-Service) to improve the accessibility and affordability of medical imaging services worldwide. The MSaaS business model enables removal of barriers of large upfront capital expenditure, lease payments and significant service expenses associated with traditional systems.

A New Standard of Care

It is clear from a host of studies that DTS offers superior performance to conventional X-rays in a wide variety of clinical applications, including some of the most common ones, e.g., thoracic, orthopaedic, head & neck, and abdominal imaging. and. It appears to offer the prospect of a cost-effective, relatively low radiation dose imaging approach to the early diagnosis and monitoring of disease. More studies are needed – and many are underway – to establish optimum imaging parameters and sensitivity and specificity indices. For many clinical applications, DTS can overcome the limitation of an X-ray and obviate a need for a CT scan, which is expensive and carries higher radiation dose. It has the potential to improve workflow and reduce the cost of imaging.

Conclusion

DTS s a promising imaging modality that acquires multiple low dose projections over a limited arc of movement of the X-ray tube and produces a stack of slices in the acquisition plane using image reconstruction. Through this, it provides depth resolution and reduces the degree of obscuration by overlying structures.

DTS bridges the gap between 2D ("conventional" or "plain" X-ray) and CT, with a lower radiation dose compared to CT, and with higher yield of clinical information compared to conventional radiography. The Nanox.ARC is intended to offer the necessary link between the two with a business model offering lower set-up cost than current expensive imaging devices. This will aid in stationing it in many facilities, offering advanced imaging to many more patients.

In conclusion, Nano-X has developed a pioneering new concept of medical imaging technology and infrastructure. Nano-X introduces a unique digital X-ray source embedded in the Nanox.ARC DTS device, coupled with the MSaaS business model among additional business models and cloud-based radiology services platform. This aims to enable the company to advance the imaging world, by creating a comprehensive accessible and affordable imaging ecosystem globally.

Figures and images:
^ Image was taken under IRB to conduct a clinical study in Israel, using our multisource Nanox.ARC system, 2023. Image courtesy of Shamir Medical Center.
^^ Image was taken under IRB permit to conduct a clinical study in Israel, using our multisource Nanox.ARC system, 2024. Image courtesy of Belinson Hospital.

Disclaimers:

- The Nanox.ARC is intended to produce tomographic images of the human musculoskeletal system adjunctive to conventional radiography, on adult patients.

- Nanox.ARC is not intended for mammographic, angiographic, cardiac, pulmonary, intra-abdominal, intra-cranial, interventional, or fluoroscopic applications.

References

[1]Vallebona A. Axial transverse laminagraphy. Radiology 1950;55:271-3.
[2]Grant DG. Tomosynthesis: a three-dimensional radiographic imaging technique. IEEE Trans Biomed Eng 1972;19:20-8.
[3]Dobbins JT 3rd, McAdams HP. Chest tomosynthesis: technical principles and clinical update. Eur J Radiol 2009;72:244-51.
[4]Dobbins JT 3rd, McAdams HP, Godfrey DJ, et al. Digital tomosynthesis of the chest. J Thorac Imaging 2008;23:86-92.
[5]Dobbins JT 3rd, Godfrey DJ. Digital x-ray tomosynthesis: current state of the art and clinical potential. Phys Med Biol 2003;48:R65-106.
[6]Bertolaccini L, Viti A, Terzi A. Digital tomosynthesis in lung cancer: state of the art. Ann Transl Med 2015;3:139.
[7]Machida H, Yuhara T, Tamura M, et al. Whole-Body Clinical Applications of Digital Tomosynthesis. Radiographics 2016;36:735-50.
[8]Langer SG, Graner BD, Schueler BA, et al. Sensitivity of Thoracic Digital Tomosynthesis (DTS) for the Identification of Lung Nodules. J Digit Imaging 2016;29:141-7.
[9]Michell MJ, Batohi B. Role of tomosynthesis in breast imaging going forward. Clin Radiol. 2018; 73(4): 358-371.
[10]Tingberg A. X-ray tomosynthesis: a review of its use for breast and chest imaging. Radiat Prot Dosimetry. 2010; 139(1-3): 100-107.
[15]National Lung Screening Trial Research Team, Aberle DR, Adams AM, et al. Reduced lung-cancer mortality with low-dose computed tomographic screening. N Engl J Med 2011;365:395-409.
[16]Grosso M, Priotto R, Ghirardo D, et al. Comparison of digital tomosynthesis and computed tomography for lung nodule detection in SOS screening program. Radiol Med 2017;122:568-74.
[17]Bertolaccini L, Viti A, Terzi A. Digital tomosynthesis in lung cancer: state of the art. Ann Transl Med 2015;3:139.
[18]Ferrari A, Bertolaccini L, Solli P, Di Salvia PO, Scaradozzi D. Digital chest tomosynthesis: the 2017 updated review of an emerging application. Ann Transl Med. 2018; 6(5): 91.
[19]Meltzer C, Båth M, Kheddache S, Ásgeirsdóttir H, Gilljam M, Johnsson ÅA. Visibility of structures of relevance for patients with cystic fibrosis in chest tomosynthesis: Influence of anatomical location and observer experience. Radiat Prot Dosimetry. 2016; 169(1-4): 177-187.
[20]Sharma M, Sandhu MS, Gorsi U, Gupta D, Khandelwal N. Role of digital tomosynthesis and dual energy subtraction digital radiography in detection of parenchymal lesions in active pulmonary tuberculosis. Eur J Radiol. 2015; 84(9): 1820-1827.
[21]Lee G, Jeong YJ, Kim KI, et al. Comparison of chest digital tomosynthesis and chest radiography for detection of asbestosrelated pleuropulmonary disease. Clin Radiol. 2013; 68(4): 376-382.
[24]Camilla Bergh et al 2020 Fracture incidence in adults in relation to age and gender: A study of 27,169 fractures in the Swedish Fracture Register in a well-defined catchment area. PLOS One December 21, 15 (12)
[25]Antono Pinto et al 2018. Traumatic fractures in adults: missed diagnosis on plain radiographs in the Emergency Department. Acta Biomed 89(Suppl 1), 111–123.
[26]Mattijssen-Horstink, L et al 2020. Radiologic discrepancies in diagnosis of fractures in a Dutch teaching emergency department: a retrospective analysis. Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine 28, Article number: 38 (2020).
[27]Blum, A et al 2018. Tomosynthesis in musculoskeletal pathology. Diagnostic and Interventional Imaging 99, 423-441.

[28]Duryea J, Dobbins JT, Lynch J. A 2003. Digital tomosynthesis of hand joints for arthritis assessment, Med. Phys 30, 325–333 (2003).
[29]Canella, C et al 2011. Use of Tomosynthesis for Erosion Evaluation in Rheumatoid Arthritic Hands and Wrists. Radiology 258, No. 1.
[30]Paolo Simoni et al 201. Use of tomosynthesis for detection of bone erosions of the foot in patients with established rheumatoid arthritis: comparison with radiography and CT. American Journal of Roentgenology 205, 364-370.
[31]Wollin Gupta et al 2018. Abdominal Radiography with Digital Tomosynthesis: An alternative to Computed Tomography for the Identification of Urinary Calculi Urology 120,56–61. 2018).
[32]Winship, B, Raudabaugh, J et al 2019. Pelvic Digital tomosynthesis for the evaluation of distal ureteral calculus: Organ- specific doses and effective dose (ED), compared with Non-contrast CT. J.Urol 201; Supplement 4, e395-396.
[33]Ceder, E et al.2016. Thoracic spine imaging: A comparison between radiography and tomosynthesis using visual grading characteristics. Radiat Prot Dosimetry 169(1-4):204-10.
[34]Geijer M et al. 2017. Tomosynthesis of the thoracic spine: added value in diagnosing vertebral fractures in the elderly. Eur Radiol 27(2):491-497.
[35]Yener N. Yeni et al 2022. Measuring the Thickness of Vertebral Endplate and Shell Using Digital Tomosynthesis. Bone. 157: 116341