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ORIGINAL ARTICLE

# Dynamic Four-dimensional Computed Tomography (4D CT) Imaging for Re-entry Risk Assessment in Re-do Sternotomy - First experience

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**Background** Repeat cardiac surgeries are well known to have higher rates of complications, one of the important reasons being injuries associated with re-do sternotomy. Routine imaging with CT can help to minimise this risk by pre-operatively assessing the anatomical relation between the sternum and the underlying cardiovascular structures, but is limited by its inability to determine the presence and severity of functional tethering and adhesions between these structures. However, with the evolution of wide area detector MD CT scanners, it is possible to assess the presence of tethering using the dynamic four-dimensional CT (4D CT) imaging technique.

**Methods** Nineteen patients undergoing re-do cardiac surgery were pre-operatively imaged using dynamic 4D CT during regulated respiration. The datasets were assessed in cine mode for presence of differential motion between sternum and underlying cardiovascular structures which indicates lack of significant tethering.

**Results** Overall, there was excellent correlation between preoperative imaging and intraoperative findings. The technique enabled our surgeons to meticulously plan the procedures and to avoid re-entry related injuries.

**Conclusions** Our initial experience shows that dynamic 4D CT is useful in risk stratification prior to re-do sternotomy by determining the presence or absence of tethering between sternum and underlying structures based on assessment of differential motion. Furthermore we determined the technique to be superior to non-dynamic assessment of retrocardiac tethering.

**Keywords** Re-do sternotomy • Four-dimensional CT • Dynamic CT • Wide area detector CT • Differential motion

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# Introduction

Re-do cardiac surgery is associated with higher incidences of morbidity and mortality. This is related to intraoperative adverse events, occurring at a frequency of around 7% and most often resulting from injuries to heart, aorta and other major vessels or bypass grafts [1].

In 1983, a review on second sternotomies reported a 2-6% incidence of catastrophic haemorrhage and the presence of dense retrosternal adhesions was thought to be a major predisposing factor [2]. Traditionally, preoperative imaging in re-do sternotomy has comprised a coronary angiogram and a lateral chest radiograph, in which a definite retrosternal clear space indicated the absence of significant adhesions. Of the 131 surgeons in the above study, only five reported using CT scans for pre-operative imaging.

Subsequently, spiral CT and, more recently, multi-slice 3D CT and CT angiography has been widely described as an excellent tool for preoperative assessment and risk stratification [3–5]. Based on a literature review in 2009, it was concluded that pre-surgical CT imaging decreases the incidence of complications and hence should be an essential component of pre-operative work-up prior to re-do cardiac surgery [6].

ECG gated contrast enhanced multi-slice CT is optimal for assessing anatomical detail of the heart, ascending aorta and coronary bypass grafts as well as their relation to the sternum [3]. It can also assess the proximity or degree of contact between sternum and anterior cardiovascular structures at the time of scanning and would thus give a rough estimate of the likelihood of significant retrosternal adhesions [7]. However, conventional static CT imaging, including 3D imaging and CT angiography, is limited in discriminating proximity or non-adherent contact, which can be easily separated during surgery, from functional tethering between sternum and retrosternal structures, which needs careful surgical planning in order to reduce the risk of intraoperative injury.

Wide field-of-view multi-detector computer tomography (MDCT) having evolved to 320 detector rows, each with a width of 0.5 mm, can cover up to 16 cm in z-axis (superior-inferior) [8]. Therefore if the region of interest to be scanned is 16 cm or less, then the scan can be undertaken without table movement resulting in wide-volume axial, non-helical imaging [9,10]. When the CT volume scan is undertaken without table movement, patient motion such as regulated active respiration can be introduced generating 4D data sets depicting motion in real time [11].

Our aim was to pioneer a study on utilisation of dynamic 4D CT for re-entry risk assessment in re-do sternotomy by determining the presence of tethering of the sternum to underlying structures.

# Methods and Materials

Our institutional review board approved this study. Twenty-two patients who were being considered for re-do cardiac surgery were referred for dynamic 4D CT, all of whom provided informed consent. The average age was 64 years and 13 of the subjects were male. Most of them had one previous sternotomy while three of them had two previous surgeries.

Imaging was performed using 320-slice MDCT (Aquilion ONE, Toshiba Medical Systems, Tochigi, Japan) with 16 cm of superior to inferior coverage in one tube rotation [8].

4D CT scans were acquired using a continuous dynamic volume scanning technique. Using the full 320 MDCT array a 16 cm z-axis volume was positioned to cover the entire sternum. Tube potential was set at 100kVp, tube current at 50 mA, gantry rotation time of 350 milliseconds, and a scan time of 5.25 seconds, resulting in an effective mAs of 17. Breathing exercises were routinely conducted prior to acquisition in order to maximise the potential to capture differential motion. Patients were instructed to take full inspiratory and expiratory breaths at a predetermined rate, which was conveyed using pre-recorded instructions via the CT scanner's automatic voice function. The resultant respiratory rate permitted two full breathing cycles within the 5.25 second acquisition time. This respiratory rate was selected because it allowed for minimal movement artefacts while ensuring the least scan time, and radiation dose, possible.

Acquisition was manually triggered when the patient was observed in full expiration, and terminated after the radiographer had observed two full respiratory cycles.

The image data was reconstructed into individual consecutive temporal 'phases' using a smooth algorithm, 1 mm contiguous slices, and a 180 degree interpolator. All 'phases' were reconstructed 175 milliseconds apart, providing a temporally contiguous representation of the 5.25 second acquisition.

Ten of the patients also had one or more coronary bypass grafts in situ. Out of these, two patients were selected based on previous imaging findings and prior surgical details to receive intravenous contrast during dynamic imaging for assessment of graft vessel relation and tethering to sternum.

The assessment of differential motion between anterior vascular/cardiac structures and the posterior sternum was undertaken on a post-processing workstation with multidimensional video analysis capability, able to generate multiple cine projections (Vitrea, Vital images, Minnetonka, Minnesota, USA). The minimum and maximum distance of key structures such as the right ventricle, right atrium, ascending aorta and innominate vein from the sternum was recorded along various phases of inspiration and expiration. This was followed by qualitative assessment of differential motion between sternum and the underlying structures as the cardiac pulsation and respiratory motion combine to cause unique motion in each structure. All of the possible planes were reviewed, including true and oblique axial, coronal, and sagittal. By utilising a consensus approach between the two reviewing radiologists, a cardio-thoracic sub-specialist and a Fellow in thoracic imaging, lack of differential movements and areas of sustained constant contact between structures were considered to indicate tethering. The sternal wires were used as reference points for describing suspicious areas to facilitate easy localisation by the surgeons on table. If the possibility of tethering was