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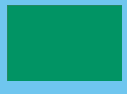

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EDITORIAL

Equilibrium radionuclide angiocardiography: Its usefulness in current practice and potential future applications

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Abstract

The routine and potential future applications of equilibrium radionuclide angiocardiography/multigated acquisition (MUGA) in clinical decision making are explored in this review. The non-invasive nature of the test, less operator dependence, lower radiation dose and ease of performing, even in ill patients, are important considerations in clinical cardiology practice. Two important routine uses of this modality in day-to-day clinical practice include the following: serial assessment of left ventricular ejection fraction (LVEF) in patients receiving cardiotoxic chemotherapy, and determination of accurate LVEF in patients with intractable heart failure. Other potential utilities of MUGA that could be translated into clinical practice include determination of regional LVEF, obtaining information about both right and left ventricle in suitable patients as a part of first pass angiocardiography, identification of diastolic dysfunction in patients with heart failure with preserved LVEF, and demonstration of dyssynchrony prior to cardiac resynchronisation, specifically by MUGA single photon emission tomography.The last two indications are particularly important and evolving at this point.

INTRODUCTION

Multigated acquisition (MUGA) of the cardiac blood pool or equilibrium radionuclide angiocardiography (ERNA) is an established modality in nuclear cardiology practice. The 99m-technetium radio-labelled red blood cells (RBCs) delineate the left ventricular (LV) cavity with high precision and aid in accurate evaluation of LV function. With the advent and routine use of gated myocardial perfusion studies (MPS) and highly improved cardiac computed tomography and magnetic resonance imaging, a number of previous applications of MUGA have almost gone into oblivion or add little to the practical management of cardiac patients at present. Use of the widely available echocardiogram with or without colour Doppler has been highly popular among internists because of its availability, ease of use and low cost. Even though the routine use of MUGA scan has reduced among the user community, its lower operator dependence and high reproducibility are of great advantage and can make this technique pivotal in the evaluation of certain cardiac conditions in routine clinical practice[1,2].

In this review, we have summarized the clinical usefulness of MUGA in today's cardiology along with some evolving applications. The review explores the role of MUGA in precise estimation of LV ejection fraction (LVEF) (both global EF and regional EF), its relevance as a part of first pass radionuclide angiocardiography (FRNA), identification of diastolic dysfunction in patients of heart failure with preserved ejection fraction (HF-PEF) and also in determining the synchronicity of LV myocardium in the decision making of cardiac resynchronisation therapy.

HOW MUGA IS PERFORMED-A BRIEF REVIEW

MUGA study, also referred to as radionuclide ventriculogram, uses 99m-technetium labelled RBC (99m-Tc RBC) to provide a relatively accurate and reproducible assessment of LVEF. One prerequisite of electrocardiographic (ECG) gating is less than 10% premature ventricular contraction and hence an ECG rhythm strip is taken before the study. The patient is injected with approximately 20 mCi of 99m-Tc RBC. The tagging is undertaken by different methods (e.g., *in vivo*/*in vitro*). The radiolabeled RBCs achieve a state of equilibrium after around 15-20 min and the patient is imaged after an interval of 30 min from injection with a gamma camera. ECG gating is carried out using R wave as a trigger. The cardiac cycle is divided into 16 or 32 frames. The correct frame rate is required to obtain a proper temporal sampling (to obtain the peaks and valleys of the cardiac cycle) and statistical sampling (to obtain proper count statistics). Usually three standard views of the heart are obtained: anterior, left anterior oblique and best septal view (in which the interventricular septum is best visualised delineating both right and LV blood pool)[3]. The scan takes approximately 20 min to be completed. The review and analysis of the data are undertaken both by qualitative and quantitative mode and by the cinematic display on the computer screen of the images with regard to the ventricular contraction and wall motion. After the initial visual assessment, a region of interest (ROI) is drawn around the LV blood pool. This ROI would generate LVEF, regional EF and various other parameters including parametric images with the aid of software analysis (the details of the parameters are described in the following sections)

FUNCTIONAL PARAMETERS OBTAINED FROM RESTING MUGA STUDY

Substantial clinically important information can be obtained from a resting MUGA study. Both the global and regional EF of LV can be calculated with high precision with the help of MUGA study. In addition, MUGA provides information about the size, position and rotation of the heart and proximal great vessels. One can also get an idea about the individual chamber size [LV, right ventricular (RV) and atria]. With regard to EF, usually a normal LVEF at rest is considered to be 50% or more. An important advantage of MUGA study is the knowledge of regional wall motion of LV and regional EF in addition to global LVEF. Regional values can be abnormal even when global ejection fraction is normal, as happens in the setting of a dyskinetic segment of myocardium. The left ventricular time activity curve (LV TAC) gives a fair estimate of contractile pattern of LV and diastolic function. A number of parametric images can be displayed which give added insight into the data described above. A stroke volume (SV) image is obtained by subtracting the end systole image from the end diastole (ED) image. SV is the amount of blood ejected out of LV per contraction. The paradox image is the atrial SV and is generated by subtracting the diastolic image from the systolic one. In this case, all negative pixels are set to zero. The phase display consists of both an image and a graph. The phase display shows us the contractile pattern of myocardium at a given point of time. The images are usually based on colour or gray scale. It helps in determination of synchronicity of LV myocardium. The amplitude image is also a colour scale/gray scale display of the magnitude of contraction of myocardium and obtained from MUGA study. Two more important parameters obtained from the LV TAC are peak filling rate (PFR) and time to peak filling rate (t-PFR). These two parameters are important considerations for diagnosing diastolic dysfunction (Figures 1-4). The clinical relevance of each parameter has been described in respective sections.

WHY MUGA IS UNIQUE

The coronary angiogram has been the gold standard for studying LV function[3] but it is an invasive procedure with high radiation burden. The facilities are not widely available and thus are expensive. Instead, the echocardiogram is a widely available tool. It is easy to perform and does not impart any radiation to the patients. The procedure can be performed even at the bed side in a sick patient as well. However, the modality is highly operator dependent and often gives inaccurate results in some specific population groups like obese and female subjects. MUGA is non-invasive in nature, easy to perform, imparts a smaller radiation burden to patients (0.3-0.52 rem equivalent in a standard MUGA study)[3] and is less operator dependent. An entire MUGA study is completed by one hour. So, it can be a reasonable alternative in clinical practice. The use of gating devices with R wave on ECG (corresponding to ED)[4] has helped in assimilating both the electrical and mechanical events of LV in a single study. Apart from routine use of LVEF determination, a MUGA study can provide diastolic parameters, mostly the PFR and t-PFR derived from the LV time activity curve. However, it is widely known that variations in heart rate affect the diastolic portion of the time

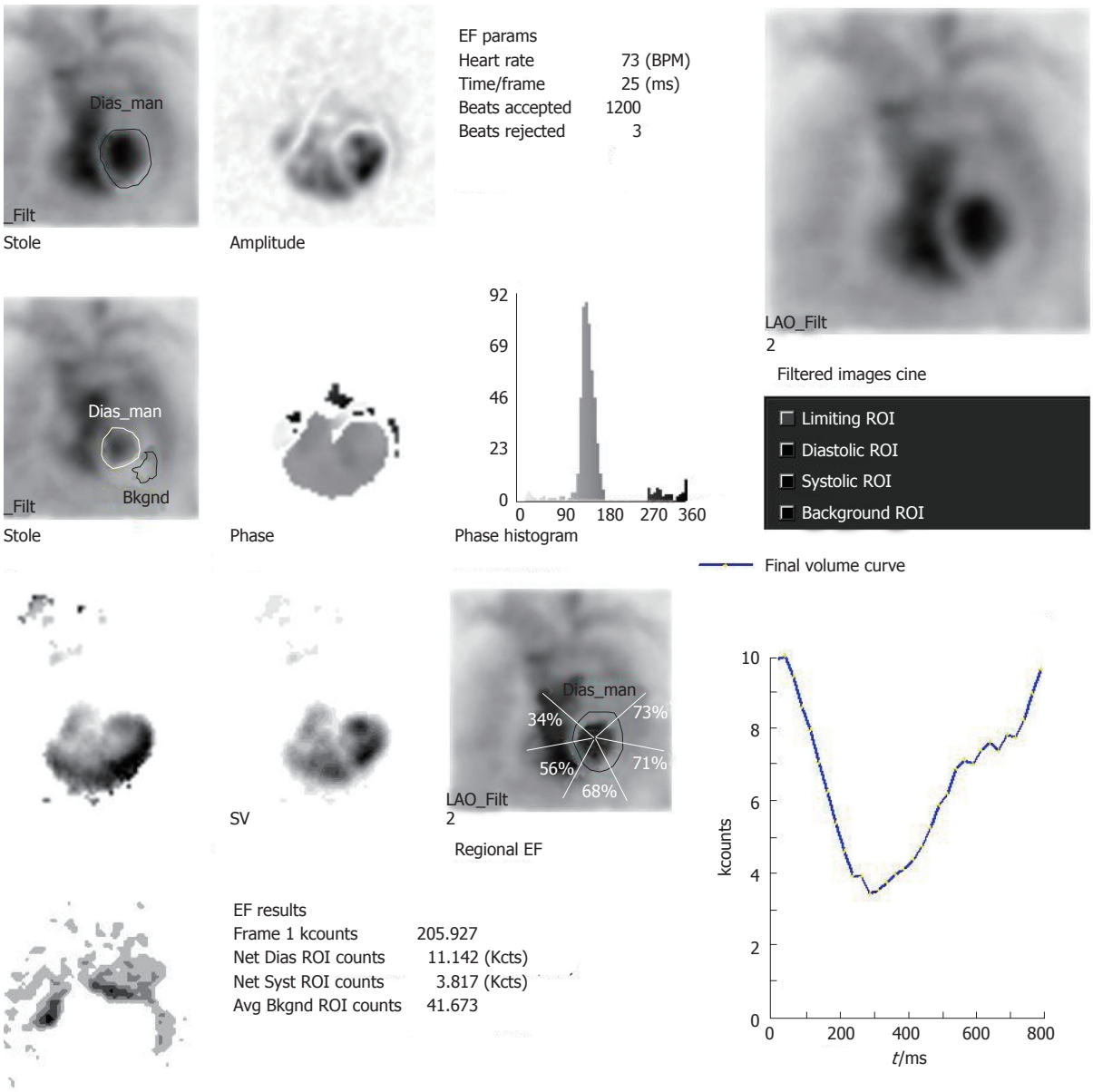

Figure 1 Normal multigated acquisition study with left ventricular ejection fraction of 66%. The phase image shows synchronous contraction across the left ventricular (LV) myocardium with narrow phase histogram width. The left and right ventricular phases are in sync with each other and out of sync with the atrial phase. The amplitude image shows maximal count variation in the lateral wall of LV myocardium suggesting maximal contraction by lateral wall and paradox image does not show any wall of LV myocardium to be in paradox. LV time activity curve is normal. EF: Ejection fraction; ROI: Region of interest; LAO: Left anterior oblique; SV: Stroke volume; Syst: Systolic; Dias: Diastolic; Avg Bkgnd: Average backgroud.

activity curve from which the PFR and t-PFR values are obtained (heart rate variations do not affect the systolic portion of the curve and therefore do not affect the calculation of ejection fraction). When a physician wishes to obtain this diastolic information the acquisition must include a narrow acceptance window of +/- 10%-15% around the average heart rate R-R interval. The acquisition time will increase proportionally with the amount of heart rate irregularity, which is required for an accurate PFR and t-PFR.

The determination of synchronicity of LV myocardium is of paramount importance in clinical decision making prior to cardiac resynchronisation therapy (CRT). Recent studies show MUGA can also help in this scenario[5] with acceptable precision as compared to speckle tracking echocardiogram. MPS can also provide information about diastolic parameters[6,7] and synchronicity of LV myocardium[8,9] in today's practice of cardiology but MPS is more expensive and it is a relatively prolonged procedure (resting MPS takes at least 2 h to be completed) compared to a MUGA study. The following sections will elaborate the strength and shortfalls of each modality in details.

Before we proceed further in the discussion, we summarise the main applications of MUGA in a tabular format (Table 1).

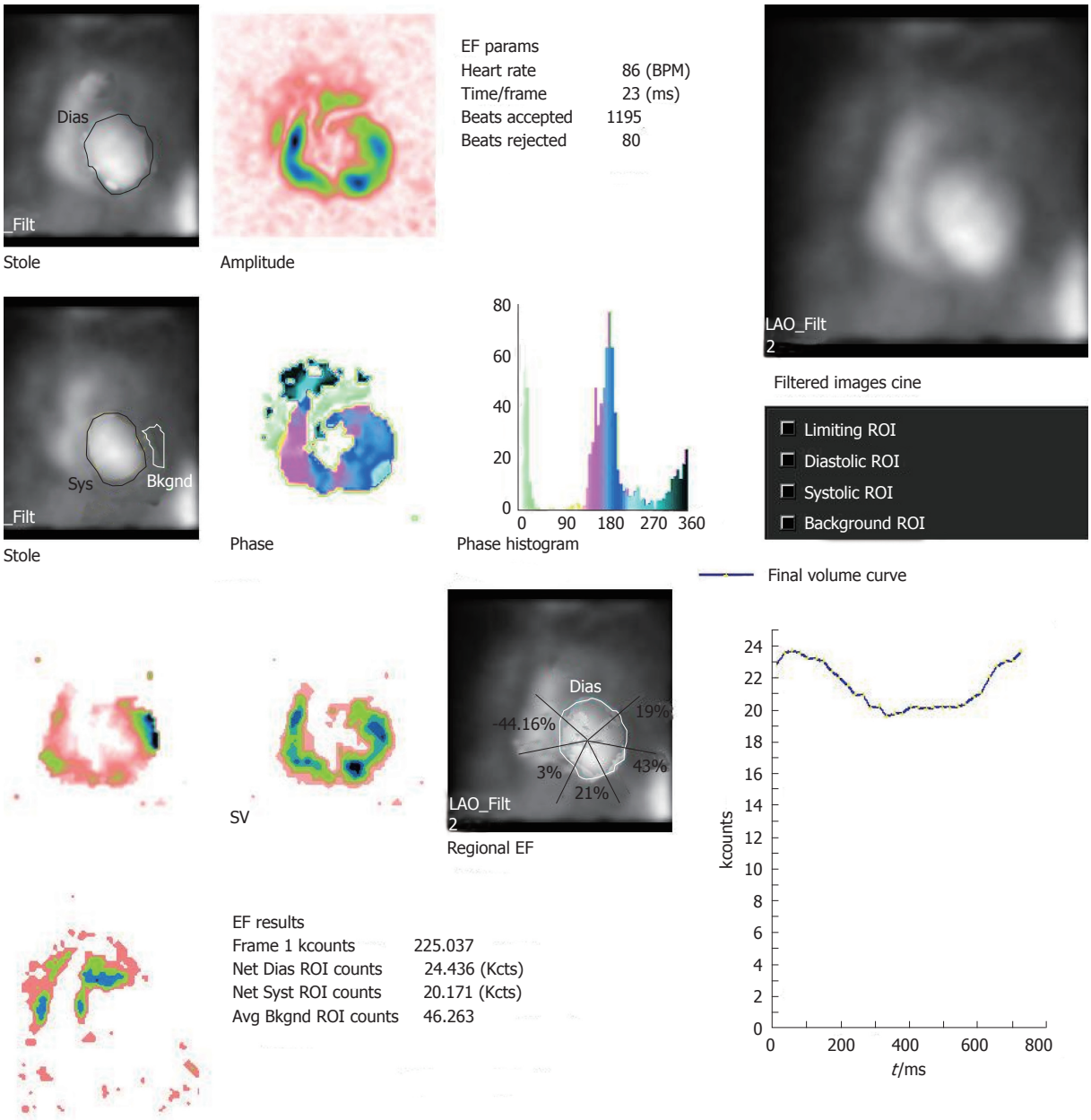

Figure 2 Multigated acquisition scan shows significantly reduced left ventricular ejection fraction of 17%. The phase image shows dyssynchronous contraction in left ventricular (LV) myocardium and there is overlap of phases both in left and right ventricular myocardium. The width of the phase histogram is more than normal suggesting intra- and inter-ventricular dyssynchrony. The image also demonstrates regional ejection fraction (EF). The paradox image does not show any region of myocardium in paradox. The left ventricular time activity curve is abnormal. ROI: Region of interest; LAO: Left anterior oblique; SV: Stroke volume; Syst: Systolic; Dias: Diastolic; Avg Bkgnd: Average backgroud..

CURRENT STATUS OF MUGA IN CLINICAL PRACTICE

EF evaluation in chemotherapy patients

Serial evaluation of LVEF in patients receiving cardiotoxic chemotherapeutic medications like anthracycline antibiotics (doxorubicin, daunorubicin, epirubicin etc), is one of the most commonly utilized indications for MUGA study. The applications of MUGA in this setting has been extensively summarised in an article by Lu[10]. It is observed that these medicines have cumulative dose dependent adverse effects on cardiac myocytes and may lead to cardiomyopathy induced congestive heart failure (CHF) due to superoxide mediated cell damage mechanisms[11-13]. Swain *et al*[13] have shown that the incidence of CHF is 5%, 26% and 48% in patients who received cumulative doses of 400 mg/m^2, 550 mg/m^2 and 700 mg/m^2 of body surface of doxorubicin, respectively. Around 450-500 mg/m^2 cumulative dose is considered a "dangerous dose" for inducing cardiotoxicity. All patients, however, are not vulnerable to the side effects in similar fashion. It depends on an individual's susceptibility to cardiotoxic anthracyclines. Hence, the beneficial effects of the anthracyclines are not to be curtailed

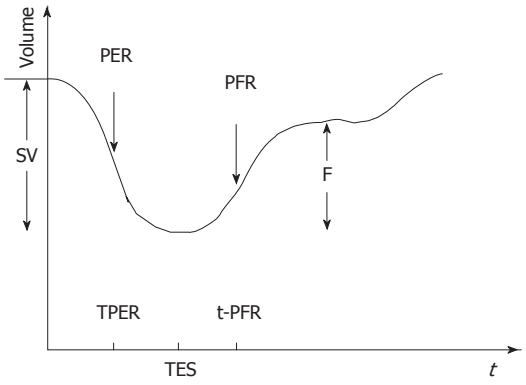

Figure 3 Left ventricular time activity curve from the first derivative showing different phases of cardiac cycle and parameters obtained. SV: Stroke volume; PER: Peak emptying rate; TPER: TIme at peak emptying rate; PFR: Peak filling rate; t-PFR: Time to peak filling rate; TES: Time to end of systole; F: Part of SV achieved during rapid filling rate.

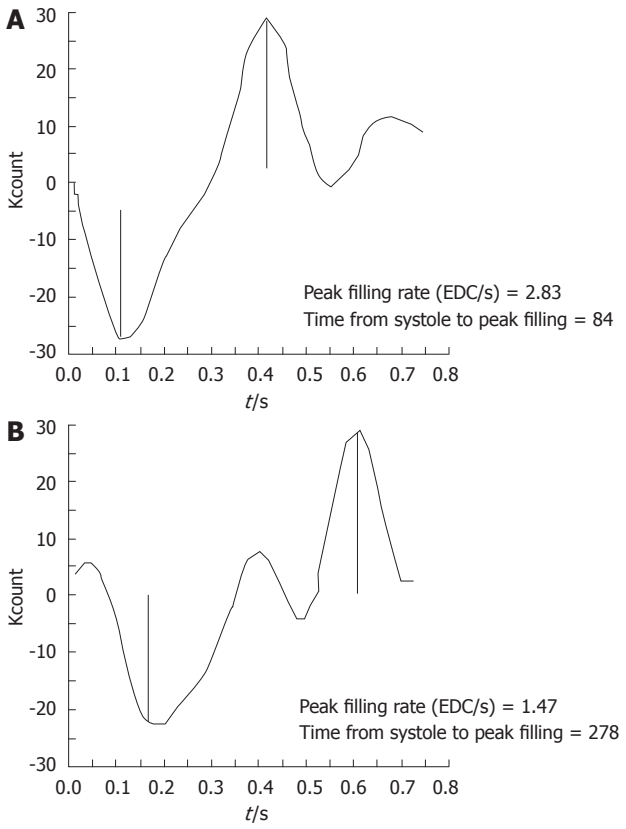

Figure 4 Multigated acquisition time activity curves with their first derivative. A: Pattern of normal diastolic function; B: One with abnormal diastolic function.

abruptly at a dose of 450-500 mg/m^2 in all patients. This has to be customised on a case to case basis, based on available cardiac parameters, mostly by measuring LVEF. The indication to discontinue doxorubicin treatment is a fall of LVEF by 10% or more and/or LVEF being 30% or less. MUGA has excellent reproducibility in determining LVEF and hence forms the basis of its serial application in the clinical setting. The determination of LVEF by MUGA does not require a particular geometric conformation of LV as required by echocardiogram or contrast angiogram and hence the assessment by MUGA is more accurate.

Guidelines for monitoring adult patients on doxorubicin are described in Table 2[14]. The monitoring of paediatric populations receiving anthracyclines is different and an echocardiogram is usually the preferred modality due to no radiation to the patients[15,16]. However, when mediastinal irradiation is necessary, the preferred approach has been described in Table 3.

Apart from systolic function, diastolic parameters can also be a predictor of depressed myocardial functions for patients on chemotherapy[16] and will be discussed in the relevant section.

EF evaluation in heart failure patients

The therapeutic decision for patients with intractable cardiac failure is crucial. Patients with end-stage heart failure require surgical management such as heart transplantation[17]. The determination of LVEF in its near exact value is thus crucial to the central decision regarding performing a surgical procedure or managing the patients conservatively. MUGA, being the most dependable methodology to determine the LVEF with minimal inter-observer variation, is definitely the method of choice[1]. Patients with chronic heart failure (HF) with LVEF < 35% are often candidates for CRT on the basis of the duration of QRS complexes on ECG[17]. There is an evolving concept of demonstration of dyssynchrony that is of paramount importance. This will be discussed under the subheading of "evaluation of dyssynchrony prior to CRT".

MUGA as a part of first pass radionuclide angiography

First pass radionuclide angiography (FPRNA) is useful in (1) evaluating cardiac shunts and (2) obtaining RVEF. This is performed by injecting the radiopharmaceutical in bolus form and analysing the usable data during the initial transit of the radionuclide bolus through the central circulation. In order to obtain RVEF, the injection should be prolonged to attain an equilibrium blood pool phase in the right ventricle[4]. The details of the FPRNA are beyond the purview of this review; however, it is important to note that FPRNA can be an addendum to a standard MUGA study. However, MUGA remains as the standard modality to evaluate the LVEF due to higher count rate[18].

MUGA as a modality to determine regional ejection fraction

MUGA is unique to demonstrate the regional EF of LV myocardium with reasonable precision[19]. The change in background corrected count in regions of LV, directly proportional to the change in blood volume, is used to determine the regional EF. Thus the regional EF is calculated from the background corrected time activity curve generated from a standard resting MUGA

Table 1 Older and recent applications of multigated acquisition

	Older applications	Recent applications	Evolving applications for routine use	Commonly employed modality in current practice
Chamber orientation	+	+/-	-	Echocardiogram
Chamber size	+	+/-	-	Echocardiogram
Rhythm abnormalities	+	-	-	Electrophysiologic studies
Global EF	++	++		Contrast angiogram, 2D echocardiogram
Regional EF	++	++		MUGA
Wall motion abnormalities	++	+/-	-	Gated myocardial perfusion scans
Diastolic function evaluation	-	+	++	Echo-Doppler with E/A measurements
Assessment of synchrony	-	-	++	Speckle tracking echocardiogram

EF: Ejection fraction; E/A wave: E wave depicts early [passive filling of left ventricular (LV)] and A wave represents active (atrial) filling of LV. Normally E>A. However, E<A is seen in diastolic dysfunction. ++: Strongly indicated; +: Indicated; +/-: Doubtful indication; -: Not indicated.

Table 2 Guidelines to perform multigated acquisition in adult patients on doxorubicin[14]

Baseline MUGA (before starting of chemotherapy or before 100 mg/m^2 dose	If LVEF is ⩽ 30% - no doxorubicin
If baseline LVEF is > 30% and < 50%	MUGA to perform before each dose
If baseline LVEF is ⩾ 50%	MUGA to perform at the dose of 250-300 mg/m^2, 400-450 mg/m^2 and thereafter before each higher dose
If the fall of LVEF from previous study is ⩾ 10% or if LVEF is ⩽ 30%	Discontinue doxorubicin

MUGA: Multigated acquisition; LVEF: Left ventricular ejection fraction.

Table 3 Guidelines for serial monitoring of left ventricular ejection fraction in pediatric patients receiving anthracyclines and mediastinal irradiation[15]

If mediastinal irradiation is < 1000 cGy	Perform echocardiogram every alternate dose of doxorubicin when dose is < 300 mg/m^2 and perform echocardiogram before each dose if the dose of chemotherapeutic agent is ⩾ 300 mg/m^2
If mediastinal irradiation is > 1000 cGy	Perform echocardiogram before each dose
When the cumulative dose of chemotherapy crosses 400 mg/m^2	Perform MUGA before any additional dose
Discontinue doxorubicin	If the fall of LVEF is ⩾ 10% from previous study or LVEF is < 55%
Follow up	MUGA at 1st year of completion of therapy and then echocardiogram yearly till next 3 years and a repeat MUGA at 5th year along with electrocardiogram yearly

MUGA: Multigated acquisition; LVEF: Left ventricular ejection fraction.

study. This method obviates the geometric assumptions needed for invasive angiographic method of EF measurement and hence becomes more reproducible in serial studies. Due to automated data processing, patient analysis can be performed within a few minutes after data acquisition. The role of cardiac MR in determining regional EF has emerged in recent times and this appears to be more accurate in the post myocardial infarction (MI) state. The role of the 2D echocardiogram and planar MUGA study in post MI is dubious due to loss of 3D information[20]. However, cardiac MR is an expensive investigation and has limitations (e.g., in patients with claustrophobia and metallic implants). The data on comparative assessment of MUGA and CMR is not available at the moment. Regional EF determinations may prove useful in assessing the natural progression of coronary artery disease, or assessing changes resulting from pharmacologic, surgical or physiological interventions.

EVOLVING APPLICATIONS FOR ROUTINE USE

Assessment of diastolic dysfunction

Diastolic function can be conceptually described by two distinct parameters like relaxation and compliance. Systolic dysfunction and low ejection fraction have been implicated for various HF patients. The concept of isolated diastolic dysfunction[21] is emerging. Growing evidence is showing a clinical entity in a large number of patients with cardiac failure who have preserved EF but have an impaired diastolic function as the aetiology of heart failure. This entity is termed as heart failure with preserved ejection fraction: HF-PEF[21]. It is estimated that approximately 50% of the heart failure population has a normal LVEF[22]. In heart failure caused by diastolic dysfunction the pathophysiology, treatment and prognosis differ from that seen in heart failure caused by systolic dysfunction. Hence, it is important to assess

quantitatively the diastolic properties of the left ventricle as well as the systolic properties of the left ventricle in the management of patients with heart failure. The current diagnostic modality routinely used for assessment of diastolic dysfunction is Doppler echocardiography which allows non-invasive evaluation of ventricular diastolic filling[23]. The trans-mitral velocity curves reflect the relative pressure gradient between the left atrium and left ventricle throughout the diastolic filling period. The progression of diastolic dysfunction in disease states can be assessed by Doppler flow velocity curves. This test gives information about early filling to atrial filling ratio (E/A), deceleration time (dT) and isovolumetric relaxation time (IVRT)[24,25].

Non-invasive and invasive procedures require mathematical assumptions about geometry of the ventricles to quantify ventricular function. Such assumptions work well when ventricular shape is maintained. When the shape of the left ventricle is distorted by infarction, severe hypertrophy or marked dilatation, the accuracy of such geometric approaches is questionable[26]. Echocardiography is operator dependent, and for this reason, following up the patients with serial echocardiography may not give accurate information[27]. A mitral inflow pattern of abnormal relaxation (early filling less than atrial filling; prolonged IVRT; prolonged dT) is commonly associated with coronary artery disease, ischemic cardiomyopathy, hypertension, LV hypertrophy and aging[28]. Alterations in loading conditions e.g. reduced preload or increased after-load can also change a normal pattern to an abnormal filling pattern. As relaxation becomes further delayed, it impinges on the early filling phase, resulting in an increase in left atrial pressure (LAP). This increased LAP causes the filling pattern to appear normal as E/A becomes > 1[26,28]. This transition zone between abnormal relaxation and restrictive filling is termed pseudo-normalization[28] and is characterized by normal diastolic filling values. In order to differentiate between normal and "pseudo-normal", evaluation of the trans-mitral flow at peak valsalva (or any manoeuvre that reduces preload such as reverse trendelenburg or nitroglycerin) and/or evaluation of pulmonary venous flow is advocated. ERNA results have higher reproducibility because there are no geometric assumptions and do not have the disadvantage of being operator dependent. Also, with the emergence of newer software and high data storage capabilities for storing high frame data, the possibility of employing MUGA in the clinical context of diastolic dysfunction is emerging and appears more feasible for routine use.

Several studies demonstrated a good correlation between 2D echocardiogram and ERNA for a reliable determination of the diastolic parameters[29,30].

It has been observed that, for diastolic function assessment, a 32 frame gated study[4] is more valuable as compared to the more commonly performed 16 or 24 frame gated studies due to better temporal resolution. The LV TAC is generated by first Fourier harmonics (Figure 2). In a patient with diastolic dysfunction, there will be prolongation of IVRT, delay in onset of rapid filling, decrease in slope of rapid filling phase and exaggerated atrial kick[31]. Quantitatively, peak diastolic filling rate can be obtained from the first derivative of the diastolic portion of the LV TAC. The lower normal limit of PFR is 2.50 end diastolic volume per second (EDV/s). In addition, t-PFR can also be expressed in milliseconds and is expected to be less than 180 ms in a normal subject. The relative contribution of atrial filling to LV filling may be quantified as the ratio of the atrial peak to the peak of the rapid filling phase on the first derivative curve. Ratios of less than 1:4 are normal[3] (Figure 3).

The PFR is calculated by taking the first derivative of the time activity curve. The first major positive peak in the first derivative curve corresponds to the point in the time activity curve at which counts are increasing at their fastest rate. It is expressed as EDV/s. The second major positive peak in the first derivative curve corresponds to the most rapidly increasing count rate during atrial systole and has been referred to as the atrial filling rate (AFR). The PFR and AFR have been shown to correspond to the E and A waves of the Doppler echocardiographic mitral velocity waveform.

Others[31] have studied various parameters in the evaluation of diastolic function by the radionuclide technique. The parameters were PFR, t-PFR, atrial contribution to filling and IVRT. Prolongation of isovolumetric time, delay and/or decrease in early rapid filling and exaggeration of atrial contribution to filling are typical disturbances of normal filling pattern. They may occur alone or in combination (Figure 4).

In addition, the LV TAC can differentiate between a restrictive cardiomyopathy and constrictive pericarditis. The clinical presentations of both these entities are confusing and it is important to differentiate between the aetiology as the treatment plans are different. The walls of the heart become rigid in restrictive cardiomyopathy leading to less compliance of LV during its filling. Constrictive pericarditis is usually a sequela of infection/inflammation of the pericardium. It can also occur subsequent to heart attack or surgery. If early diastolic filling is delayed in a MUGA study, it indicates restrictive disease whereas if it is very rapid, it is suggestive of constrictive disease[3].

Assessment of dyssynchrony prior to cardiac resynchronization therapy

CRT, also known as biventricular pacing, is a definitive therapy for patients with intractable heart failure. The selection of patients for CRT is crucial and it depends upon the fulfilment of the following criteria[17]: (1) HF of New York Heart Association grading of heart failure grade Ⅲ/Ⅳ; (2) LVEF < 35% and (3) prolonged QRS (≥ 120 ms) on ECG. A wide QRS complex is a surrogate marker for mechanical dyssynchrony used to select

CRT patients. Baseline QRS duration is a good marker of inter-ventricular dyssynchrony, but left intra-ventricular dyssynchrony, which is a more accurate predictor of CRT response, does not correlate with baseline QRS duration[32]. With the use of these selection criteria it is shown that 30% of patients do not show an improvement in their heart failure status even after CRT. So, it is not the prolonged QRS, but rather demonstration of dyssynchrony, that is more important in selecting patients for CRT. A handful of studies have shown that speckle tracking echocardiogram/tissue Doppler imaging is a good modality to demonstrate dyssynchrony by showing lateral to septal delay[33]. A recent multicentre trial has demonstrated inconsistencies in predicting the outcome of CRT on the basis of echocardiographic parameters[34]. Hence, MUGA scan, MUGA single-photon emission computed tomography (SPECT) in particular, is equally efficient in demonstrating dyssynchrony in the LV myocardium and help in taking decisions for CRT. In particular the phase image in MUGA is mostly helpful in diagnosing dyssynchrony. Each phase angle corresponds to a temporal event and thus provides information on synchronous or dyssynchronous patterns. The mean and SD of LV Ø (SD Ø), derived from first harmonic phase analysis and the phase histogram of the ventricular time activity curve in ERNA, have been applied to characterize synchrony[35]. Novel, objective measures of regional contraction and global mechanical synchrony, the synchrony (S) and entropy (E) parameters have been developed and applied to planar ERNA as a tool for evaluation and management of HF patients. S expresses the efficiency of contraction within a region of interest (ROI). S can estimate the contraction potential if the ROI is synchronized. E measures the degree of randomness within the ROI, from 0, with synchronous motion and a single Ø, to 1 with fully dyssynchronous contraction[35,36]. It is designed to differentiate between forms of extremely variable regional dyssynchrony. In preliminary clinical protocols normal values were established and these measures were shown to enhance CRT patient selection, to predict and quantitate CRT outcomes, to optimize CRT pacemaker lead placement based on location of the latest contracting segment, to assess synchrony in HF patients with narrow QRS, and to measure RV synchrony[35,36]. With the phase image from which they are derived, the latest contracting segment can be localized and CRT pacemaker location optimized. Additionally, the importance of RV synchrony can be evaluated over a spectrum of cardiac pathology. As noted by the authors, further studies assessing the ability of these parameters to predict CRT outcome are required and application of the method to SPECT ERNA could add greater resolution and accuracy.

SPECT MUGA

This is an upcoming modality and increasingly more studies have been published in this domain in recent times. The advantage of this technique is the absence of the necessity of a background subtraction in generating the LV TAC, as in the case of planar MUGA study, thus being less liable to manual error[37]. Automatic or semi-automatic programmes which are inherently volumetric and consider LV as a 3D object are the current standard. The timing of the scan is similar to that of planar study i.e., 30 min after the injection of radiolabeled blood cells. Instead of planar acquisition for standard MUGA study, gamma camera heads are rotated around the patient's body to obtain data from different angles. Usually 180 degree acquisition is performed. The R wave gating and beat window acceptance is kept similar to that of a standard resting MUGA study. The data are then processed with an optimum filtered back projection method to provide short axis oblique slices. With the help of software, different parameters are obtained, including LV volume curve, LVEF, RVEF, LV emptying, RV emptying, LV volumes as well as synchronicity of LV myocardium (i.e., phase histogram)[3]. LVEF obtained from SPECT MUGA study is 7-10 units higher than that obtained from planar MUGA study due to complete removal of all activity from left atrium. This factor must be considered for applying the SPECT MUGA LVEF values in the evaluation of chemotherapy patients where standards have been established using planar techniques[38]. The RV parameters and wall motions are better analyzed on SPECT MUGA. It is a useful modality for the assessment of LV and RV activation sequence and identification of the sites of atrio-ventricular nodal bypass tracks, as well as LV and RV arrhythmias[38]. The newer application of SPECT MUGA is to determine the synchronicity of LV myocardium in HF patients as described earlier for guiding them for CRT[37].

In conclusion, the data supporting potential applications of MUGA in diagnosing diastolic dysfunction and LV dyssynchrony are emerging at present; these could be translated into clinical practice. Due to higher inter-observer reproducibility and precision, MUGA is more reliable and easy to apply method for the estimation of LVEF especially in patients receiving cardiotoxic chemotherapy and in patients with intractable heart failure as compared to commonly practiced 2D echocardiogram.

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BRIEF ARTICLE

A dose comparison survey in CT departments of dedicated paediatric hospitals in Australia and Saudi Arabia

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Abstract

AIM: To measure and compare computed tomography (CT) radiation doses delivered to patients in public paediatric hospitals in Australia and Saudi Arabia.

METHODS: Doses were measured for routine CT scans of the head, chest and abdomen/pelvis for children aged 3-6 years in all dedicated public paediatric hospitals in Australia and Saudi Arabia using a CT phantom measurement cylinder.

RESULTS: CT doses, using the departments' protocols for 3-6 year old, varied considerably between hospitals. Measured head doses varied from 137.6 to 528.0 mGy·cm, chest doses from 21.9 to 92.5 mGy·cm, and abdomen/pelvis doses from 24.9 to 118.0 mGy·cm. Mean head and abdomen/pelvis doses delivered in Saudi Arabian paediatric CT departments were significantly higher than those in their Australian equivalents.

CONCLUSION: CT dose varies substantially across Australian and Saudi Arabian paediatric hospitals. Therefore, diagnostic reference levels should be established for major anatomical regions to standardise dose.

Key words: Computed tomography; Paediatric; Dosimetry; Radiation dose

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INTRODUCTION

The use of computed tomography (CT) as a diagnostic tool has dramatically increased[1], and with it, the radiation exposure to the general population, which may be a public health issue in the future[2]. Approximately 62 million CT examinations were performed in the United States in 2006, and the numbers are growing at 10% per annum; 4 million CT scans (approximately 6.5%) were performed

on American children[1,3]. In Australia between 1996 and 2010, total CT scan numbers have increased 2.8-fold, and paediatric CT scan examinations have had a 2.4-fold increase[4]. Japan, the United States of America and Australia lead the world in the number of CT scanners, with 64, 26 and 18 scanners per million citizens, respectively[5]. The number of CT scans is reportedly growing at about 9% each year in Australia[6]. It is estimated that CT scanning in Australia accounts for 65% of the population' s medical radiation exposure[7]. In 2006, an estimated 13.5 million radiological procedures were undertaken, and approximately 2.4 million of these procedures were CT scans[4]. Schauer *et al*[8] suggest that because of this increase in CT referrals, and the relatively heavy dose contribution from CT, the risks to the population from ionising radiation will also increase.

Approximately 33% of all paediatric CT examinations are in children aged ten years old or younger, with 17% in children aged five or younger[9]. At these ages, the organs and tissues are intrinsically more sensitive to oncogenic effects of radiation due to the far higher proportion of cells that are dividing and reproducing[10-12]. The radiation-induced risk is also higher in paediatric patients due to wider and increased cellular distribution of red bone marrow, and their greater post-exposure life expectancy[13,14]. The effective radiation doses received by children are about 50% higher than those received by adults for the same acquisition protocols, due to their smaller body size and related attenuation[15]. It is crucial for radiographers and radiologists to understand how CT dose relates to radiation bio-effects. With the growing popularity of CT, and the associated risks of radiation exposure, the need for national comparative CT dose survey data is clear.

Diagnostic reference levels (DRLs) are used for comparison of CT doses from different hospitals and to encourage CT departments to reduce their patient radiation dose levels[16]. A DRL, as first defined by the International Commission on Radiological Protection (ICRP), is "a form of investigation level, applied to an easily measured quantity, usually the absorbed dose in air, or tissue-equivalent material at the surface of a simple phantom or a representative patient"[17]. The ICRP recommended the establishment of DRLs in order to allow CT departments to compare their dose levels to national or regional standards. Using a specified dose measurement protocol and phantom, the DRL is usually defined as the 75th percentile of the data distribution[18]. This identifies the departments which lie above the DRL as those in which dose reduction would have the greatest impact. Since the DRL will always be breached by 25% of the population, the DRL should be used as an indication rather than a proof of excessive dose[19].

The use of DRLs has reduced the overall dose and the range of doses observed in clinical practice in the United Kingdom, with a 50% decrease in average dose between 1985 and 2000[20,21]. To achieve similar outcomes in Australia, DRL surveys must initially be conducted[19]. This paper describes the conduct and results of the first survey of public paediatric hospitals in Australia and Saudi Arabia.

The objective of this research was to obtain doses from common paediatric CT scan examinations in Australia and Saudi Arabia using a simple dose measurement method. From these data, a simple ranking method, similar to those used in DRL methods, was used so that staff in CT departments undertaking paediatric examinations can use this method to compare their CT scan factors against the dedicated paediatric CT scanners.

An additional objective was to compare measured dose data with the dose information that was displayed on the CT console, which should be a regular part of quality assurance procedures. This comparison would assure paediatric CT staff of their ability to evaluate their doses from console data.

MATERIALS AND METHODS

Radiation dose measurements were obtained for CT scan examinations of the head, chest and abdomen/pelvis using existing departmental protocols for children aged 3-6 years from all public paediatric hospitals in Australia (designated A1 to A7) and Saudi Arabia (designated B1 to B8) [see Table 1 for details of CT scanners; note that eight models of CT scanner (1, 6, 16 and 64 slices), manufactured by four different companies, were in use at the 15 participating hospitals]. This age range was selected due to the availability of data for all paediatric hospitals participating in the study, and also because this is a popular age for paediatric injuries resulting from trips and falls. Scans were performed in the departments' own CT scan units using a CT phantom measurement cylinder of 16 cm diameter[22].

The phantom was scanned using department protocols for each region and dose was recorded using a DIADOS dosimeter and 100 mm long free-air ionisation chamber (PTW DIADOS, Freiburg, Germany). The recorded charge, in nC, was converted to mGy·cm using an established conversion factor. The phantom was scanned over a range of 100 mm, placing the CT probe only in the central chamber. The purpose of scanning over this volume was to eliminate differences due to slice/beam thickness, number of slices and pitches between each department's protocols. Each CT scan used the department "routine" protocol for each anatomical region and was repeated for a total of three measurements. For all hospitals and scan regions, the three measurements were found to agree to within 0.5% error. Where provided by the CT manufacturer, volume computed tomography dose index ($CTDI_{vol}$) and/or dose length products (DLP) were recorded for each scan.

From the dosimetry data, reference levels (RLs) were calculated using the developed RL methodology for each CT anatomical region in each country. The RL methodology is similar to DRL, where dosimetry data is placed in rank order. The 75th percentile was used as a RL

Table 1 Computed tomography units within hospitals

Country	Hospital code	Manufacture	Model	No. of rows of detectors
Australia	A1	Siemens	Sensation	16
Australia	A2	Philips	Brilliance	64
Australia	A3	General electric	Light speed VCT	64
Australia	A4	Toshiba	Aquilion	64
Australia	A5	Philips	Brilliance	64
Australia	A6	Siemens	Somatom sensation	64
Australia	A7	Toshiba	Aquilion	16
Saudi Arabia	B1	Toshiba	Aquilion	64
Saudi Arabia	B2	Siemens	Emotion	1
Saudi Arabia	B3	General electric	Light speed VCT	64
Saudi Arabia	B4	Siemens	Somanta	6
Saudi Arabia	B5	General electric	Light speed	16
Saudi Arabia	B6	General electric	Hispeed	4
Saudi Arabia	B7	Siemens	Emotion	1
Saudi Arabia	B8	Siemens	Emotion	1

VCT: Volume computed tomography.

threshold, with hospitals above this value being classified as delivering "high" doses[19].

To determine whether there was a statistically significant difference between the Australian and Saudi Arabian hospital CT protocols for each anatomical regions (head, chest, abdomen/pelvis), the measured doses were compared using Student's *t*-tests (in MINITAB v16) with the confidence level set at 95%. The definition used for an outlier data point is a point which falls more than 1.5 times the interquartile range above the third quartile, or below the first quartile[23].

RESULTS

Figure 1 shows the mean head dosimetry measurements delivered in the seven Australian and eight Saudi hospitals.

The measured head doses from paediatric CT scan protocols in the Australian hospitals had greater range than the Saudi Arabian scans. Nevertheless, the Australian data include a cluster of six doses in the range 137.6 to 315.1 mGy·cm with an outlier at 528 mGy·cm, being the only dose produced by an Australian CT head scan protocol above the 75th percentile DRL. The RL is exceeded in three of the eight Saudi Arabian hospitals sampled; indicating that the Saudi dose distribution is skewed to the right of the Australian distribution. As can be seen in Figure 1, five of the six highest CT head scan doses are from Saudi Arabian CT departments.

The measured head doses given by standard paediatric CT protocol in the Saudi Arabian hospitals varied from just below 200 mGy·cm to 416.3 mGy·cm. The variation in the range of doses from CT head scan protocols in Saudi Arabian paediatric hospitals is less than that in Australian paediatric hospitals.

With the exception of hospital A7 at 528.0 mGy·cm, measured Australian paediatric CT head scan doses were lower than most Saudi Arabian doses, although the overall variation in Saudi Arabian paediatric CT head scan doses was less than observed in the Australian data. The mean Australian paediatric CT head scan dose was not significantly lower than the mean Saudi Arabian paediatric CT head scan dose by 2-sample Student's *t*-test (280.1 mGy·cm *vs* 323.3 mGy·cm, $P = 0.438$); however, when the sole Australian outlier was removed, the difference was weakly significant (238.8 mGy·cm *vs* 323.3 mGy·cm, $P < 0.10$).

The Australian paediatric CT chest data are similar in distribution to the CT head data, in that there is an overall lower grouping with six hospitals delivering standard doses in a small range between 21.8 mGy·cm and 53.1 mGy·cm. The 75th percentile for the Australian hospitals was at 52.1 mGy·cm.

The CT chest doses given by standard paediatric CT protocol in the Saudi Arabian hospitals varied from below 30 mGy·cm to 84.5 mGy·cm. The 75th percentile for Saudi Arabian hospitals was at 77.8 mGy·cm. As can be seen in Figure 2, five of the six highest doses are from Saudi Arabia.

Generally, the Australian CT chest doses were lower than most Saudi Arabian doses. The mean measured Australian chest CT dose was not significantly lower than the mean Saudi Arabian dose by 2-sample Student's *t*-test (41.7 mGy·cm *vs* 60.3 mGy·cm, $P = 0.127$).

The distribution of Australian mean abdomen/pelvis radiation doses shown in Figure 2 is different to that shown in Figure 1A (head) and 1B (chest), with four hospitals clustered tightly at the low end of the range (24.9-36.4 mGy·cm), a fifth hospital (A6) in the middle of the range at 72.8 mGy·cm, and two larger values at over 100 mGy·cm each.

Note that the highest values (A2 and A5) were also the hospitals which delivered the highest measured doses for chest scans (Figure 3). The 75th percentile for Australian hospitals was at 113.9 mGy·cm. The CT abdomen/pelvis doses given by standard paediatric CT protocol in the Saudi Arabian hospitals varied from below 30 mGy·cm to 111.1 mGy·cm - an increase by a factor of nearly four. The 75th percentile for Saudi Arabian hospitals was at 81.7 mGy·cm. Unlike the head and chest dose distributions, the Saudi Arabian abdomen/pelvis 75th percentile value is lower than the Australian 75th percentile value.

As can be seen in Figure 1B, four of the six highest abdomen/pelvis doses are from Saudi Arabian CT departments, and four of the five lowest doses were from Australian CT departments. Figure 4C shows an unusual distribution of radiation doses, with clusters around 30.0 mGy·cm, 70.0 mGy·cm and 115.0 mGy·cm. Saudi and Australian doses exhibit very similar ranges, although four of seven Australian doses are in the 30 mGy·cm cluster. The mean Australian abdomen/pelvis CT dose was not significantly different from the mean Saudi Arabian abdomen/pelvis dose (61.1 mGy·cm *vs* 69.4 mGy·cm, $P = 0.637$). Figure 3A combines the

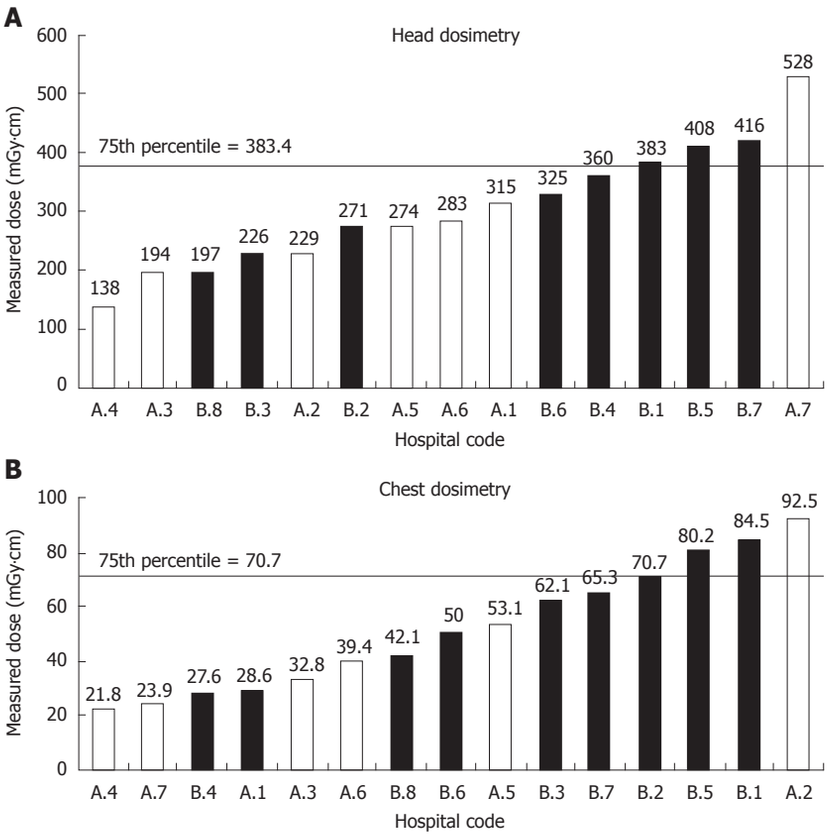

Figure 1 Mean head computed tomography dosimetry measurements from Australian and Saudi Arabian paediatric public hospitals. A: Head; B: Chest.

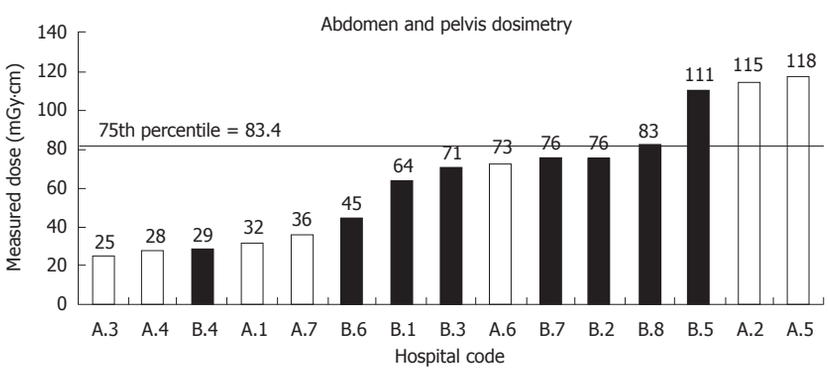

Figure 2 Mean abdomen/pelvis computed tomography dosimetry measurements from Australian and Saudi Arabian paediatric public hospitals.

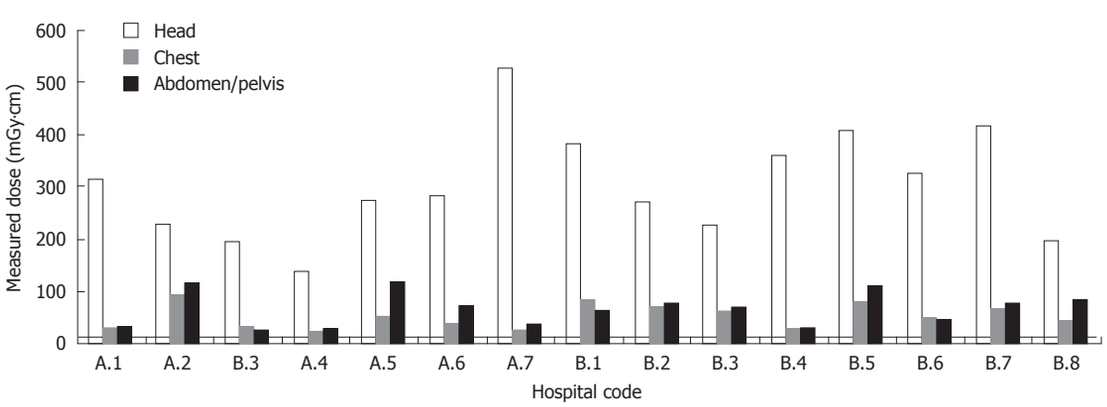

Figure 3 Combined mean dosimetry measurements from Australian and Saudi Arabian paediatric hospitals for head, chest and abdomen/pelvis.

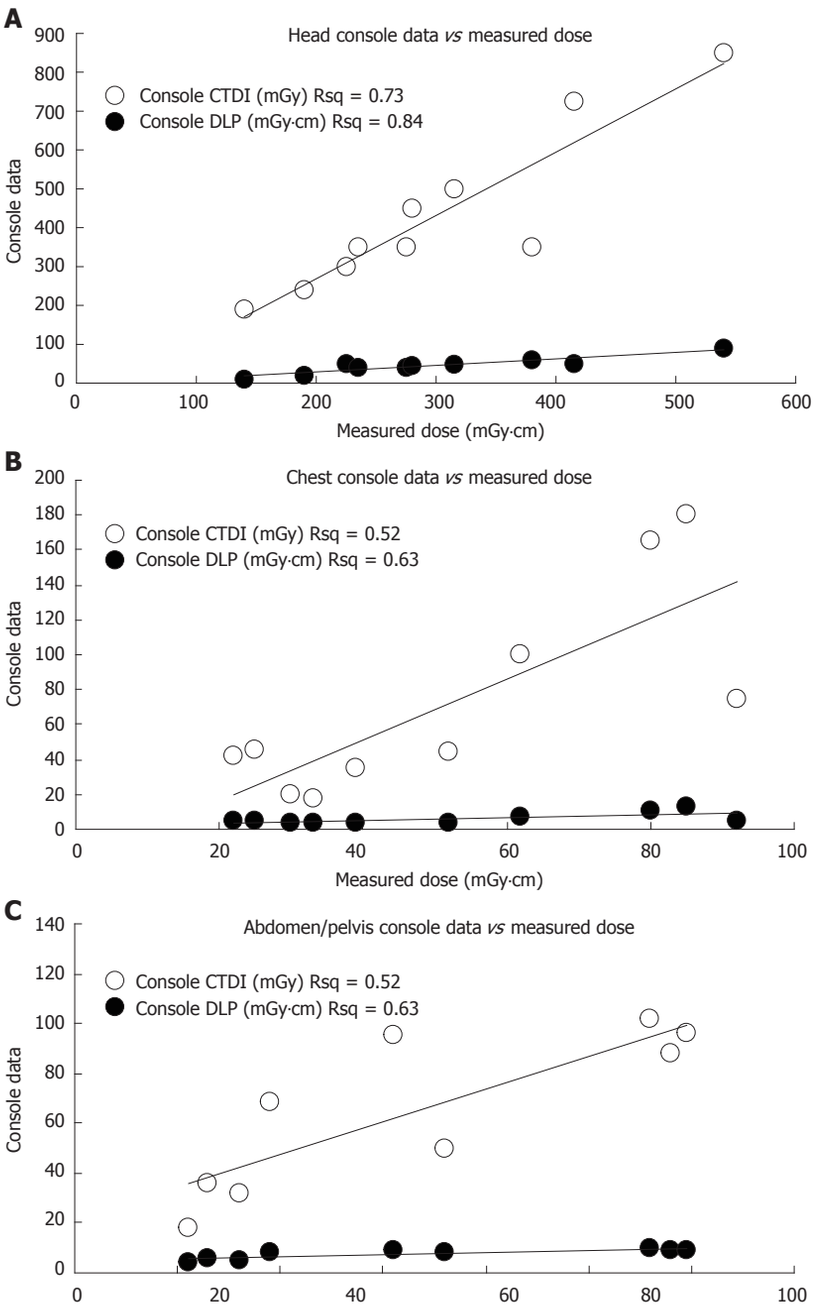

Figure 4 Correlation between computed tomography console data and measured dose. A: Head scans; B: Chest scans; C: Abdomen/pelvis scans.

resulting data in Figures 1 and 2. This provides an alternative perspective in tracking each institution's performance across different protocols. The 75th percentile line is also included for each protocol: head, chest and abdomen/pelvis.

Head, chest and abdomen/pelvis region CT dosimetry readings were analysed to determine whether there was any difference between single-slice and multi-slice CT scanners. Using 2-sample Student's *t*-tests, it was found that there was no statistically significant difference between the dose distributions for single-slice and multi-slice CT machines in the head ($P = 0.895$), chest ($P = 0.435$) or abdomen/pelvis ($P = 0.151$) dosimetry data.

Dose data, as provided by the manufacturer in the CT console, were obtained from 10 of the 15 CT scanners. Five of the CT scanners did not have facilities to display DLP and $CTDI_{vol}$ information as these were older CT scanners, and as such, data were not able to be recorded. Figure 4 compare measured dose to the DLP and $CTDI_{vol}$ information from head, chest and abdomen/pelvis region, respectively.

DISCUSSION

This paper describes the first study of direct measurements of CT radiation doses in multiple dedicated paediatric hospitals conducted in Australia and Saudi Arabia. The authors measured doses delivered in CT depart-

ments in seven Australian and eight Saudi Arabian public paediatric hospitals for three common CT examinations (head, chest and abdomen/pelvis).

The methodology chosen to measure the CT doses is not that which is usually used to obtain DRLs. The method used here was chosen in order to simulate clinical examinations and then to compare paediatric CT scanners. In using this method, the dose reading does not just become dependent upon factors such as beam energy (kVp) and tube current (mA) in the departments but also on the CT protocols such as the choice of slice/beam thickness, number of slices within the 100 mm volume used and the pitch factor selected. In choosing this method, it is hoped that this careful approach to measure dose and the subsequent comparison with data provided on the CT console of DLP and $CTDI_{vol}$ will enable others to compare their dose reading to the RL obtained from dedicated paediatric CT scanners. One limitation of the approach used in this study is that at each end of the 100 mm long scan section, full scatter conditions are not present and so this may explain the discrepancy between measured dose and console data.

The results show that there is large variation between hospitals in CT doses delivered from standard protocols for patients aged 3-6 years and that these mean doses (delivered in Australian and Saudi Arabian CT departments) are significantly different (after discarding outlying observations). The fact that such large variation in dose was discovered in paediatric CT scan protocols makes these results particularly important, as children are more susceptible to harm from radiation[15].

Previous research involving estimated doses, based on CT protocols used in the United Kingdom, found that there was substantial variation in the paediatric CT doses delivered by different hospitals[24]. Our confirmation of the results of Shrimpton *et al*[24] highlights the importance of reducing excessive CT radiation exposure. For example, the head scan from hospital A7 delivered 3.8 times more radiation than that of hospital A4, and the abdomen/pelvis scan from hospital A5 delivered 4.7 times more radiation than that of hospital A3 - both deemed by their respective departments to produce images of adequate quality.

Dose RLs for CT are useful tools for lowering radiation levels[17], but have only recently become a priority in Australia. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) was recently tasked with generating representative national DRLs for diagnostic imaging modalities that use ionising radiation[19]. At the time of writing, ARPANSA was in the process of finalising sampling and data collection procedures[25].

The differences between the measured dose delivered in Australian and Saudi Arabian CT departments are likely to be due to different levels of radiographer education, awareness of radiation dose and protocols[26,27]. Other researchers have found that understanding of the factors that affect patient doses in CT has a large impact on delivered dose, and is usually considered as the first step in optimisation strategies[28]. A 1998 study observed a variation of 10%-40% in the typical dose between individual scanners, largely due to imaging technique[29]. Mettler *et al*[30] pointed out that radiographers' basic education and training overlooks paediatric CT radiation doses. The International Atomic Energy Agency recommends education and training of radiographers involved in paediatric CT[31].

The level of awareness within the radiography community of potential risks of CT radiation also plays a major role in dose levels. According to a recent survey[26,27], most Australian and Saudi Arabian radiographers lack education about - and awareness of the importance of - radiation dose in paediatric CT. Similarly, a recent survey of health professionals in Northern Ireland regarding awareness of the radiation doses imparted during common diagnostic imaging procedures and their long term impact on patients demonstrated a knowledge gap which could be improved with appropriate training[32]. A 2006 survey in New South Wales (Australia) showed the need for continuing education in paediatric CT examinations[33].

The results also show a variation of RL ranking within hospitals. Hospital A5 achieved a low comparative dose ranking for CT protocols of the head and chest, yet provided the highest recorded dose for the abdomen/pelvis CT examinations. The situation was similar for hospital A7, whose head CT scan doses were the highest, yet they had comparatively low doses for their chest abdomen/pelvis CT examinations. This further highlights the need for vigilance in examining CT doses across the entire range of examinations.

There was good correlation between the measured dose and recorded $CTDI_{vol}$ and DLP for paediatric CT head scans ($P = 0.836$ and $P = 0.727$, respectively), but the correlation for chest and abdomen/pelvis scans was poor. Our calculations indicate that the DLP was an average of 30% larger than the measured dose for any given scan. This discrepancy may be due to the size of phantom used in this study compared to the size of patient assumed by the console calculations, which may be a difference of 32 cm. This is supported by the observations of Siegel *et al*[34] (Figure 3) and Shrimpton *et al*[24] who found that dose measurements decrease with the increasing size of phantom. Individual facilities might be well advised to confirm agreement between console data and external measurements of their own scanner at commissioning and routine quality assurance. Departments considering reviewing their routine head CT scan doses can, with a high level of confidence, use their own $CTDI_{vol}$ and DLP measurements over 100 mm and determine where they are ranked against dedicated paediatric CT scanners.

To reduce CT radiation dose levels, it is important to regularly review and update CT protocols. A recent survey in Australia showed the need for regular protocol review for paediatric CT examinations[33]. This point was also made following a 2009 survey of Syrian CT depart-

ments, which recommended the establishment of national DRLs[35]. CT protocols must acknowledge the fact that manufacturers provide varying protocol guidelines for different technologies, and that these variations can greatly affect dose. Finally, each CT scan should have a clear medical justification to ensure that the overall CT dose delivered to the population is kept as low as practicable[36].

The results presented in this article show that paediatric CT dose variation is substantial across Australian and Saudi Arabian dedicated paediatric hospitals. Also, hospitals can achieve a low comparative DRL ranking for some CT protocols (e.g., chest or abdomen/pelvis), but have a high ranking in others (e.g., head). If such internal and external dose differences can occur in dedicated paediatric CT departments, then it can be assumed that with less specific paediatric CT training and protocol development, a greater range of doses will occur in CT departments that only undertake occasional paediatric CT examinations. DRLs should be established for each major CT scan region and specifically for paediatric patients in order to find and correct such dose delivery variation.

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COMMENTS

Background

Multi-detector computed tomography (MDCT) has improved the ease, and reduced overall examination time, when imaging paediatric patients. If MDCT is not wisely used, the parameters selected may actually provide a high radiation dose to paediatric patients.

Research frontiers

Diagnostic reference levels (DRLs) are used for comparison of computed tomography (CT) doses from different hospitals. These can be used to encourage CT departments to reduce radiation dose levels. In this study, the authors have used a number of calculations [including DRLs and dose length products (DLPs)] to compare radiation doses delivered to paediatric patients at dedicated paediatric centres in Australia and Saudi Arabia.

Innovations and breakthroughs

A CT phantom measurement cylinder was provided to paediatric centres. The data collected allowed the authors to compare radiation doses used in paediatric CT examinations. Overall, dedicated paediatric centres in Australia provided less radiation dose for their paediatric CT examinations than those in Saudi Arabia.

Applications

The education and training of Australian radiographers were identified and acknowledged as providing an important contribution to understanding of dose minimisation techniques, while maintaining diagnostic image quality. To minimize variations in radiation dose delivered to paediatric patients, it is recommended that DRLs be established for paediatric body regions commonly scanned with CT.

Terminology

Further to the definition of CT DRL provided in this text, the definitions and understanding of the following will be of benefit in aiding a radiographer to minimize radiation dose to paediatric patients: computed tomography dose index (CTDI), is a calculation based on the absorbed dose in a cylindrical shaped phantom; CTDI volume is the term used to express the radiation dose to a specific volume slice, on a standard phantom; DLP is the CTDI volume multiplied by the length of the scan.

Peer review

In this work, the authors present a survey of effective doses between hospitals in Saudi Arabia and Australia with the aim of demonstrating the need for the implementation of dose reference levels and continuous education to the staff of the hospital regarding the minimization of dose according to the ALARA principle. The introduction describes the background and aims adequately and the method's section gives a concise description of the procedure followed in the study. While it does not produce new insights in the matter of radiation protection, it is a good precursor article for setting the context for decision making bodies to improve radiological practices in the sensitive area of pediatric radiology.

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CASE REPORT

Volvulus of the ascending colon in a non-rotated midgut: Plain film and MDCT findings

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Abstract

Colonic volvulus is a relatively uncommon cause of large bowel obstruction usually involving mobile, intraperitoneal, colonic segments. Congenital or acquired anatomic variation may be associated with an increased risk of colonic volvulus which can occasionally involve retro-peritoneal segments. We report a case of 54-year-old female who presented to our Institution to perform a plain abdominal film series for acute onset of cramping abdominal pain. Both the upright and supine films showed signs of acute colonic obstruction which was thought to be due to an internal hernia of the transverse colon into the lesser sac. The patient was therefore submitted to a multi-detector contrast-enhanced computed tomography (CT). CT findings were initially thought to be consistent with the presumed diagnosis of internal hernia but further evaluation and coronal reformatting clearly depicted the presence of a colonic volvulus possibly resulting from a retro-gastric colon. At surgery, a volvulus of the ascending colon was found and a right hemi-colectomy had to be performed. However, a non rotated midgut with a right-sided duodeno-jejunal flexure and a left sided colon was also found at laparotomy and overlooked in the pre-operative CT. Retrospective evaluation of CT images was therefore performed and a number of CT signs of intestinal malrotation could be identified.

Key words: Colonic volvulus; Intestinal malrotation; Abdominal plain film; Multi-detector computed tomography; Large bowel obstruction

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INTRODUCTION

Colonic volvulus is a relatively uncommon cause of large bowel obstruction accounting for almost 5% of all cases of intestinal obstruction and 10% of colonic obstruction. It usually involves mobile, intra-peritoneal, colonic segments such as the cecum, transverse colon and sigmoid colon[1].

Congenital (e.g., malrotation) or acquired (e.g., abdominal surgery) anatomical variations may be associated with an increased risk of colonic volvulus. Malrotation, in particular, includes a broad spectrum of fixation anomalies of the small and large bowel occurring when the midgut fails to complete the required 270° counter-clockwise rotation during the embryologic development[2]. This can lead to different degrees of malrotation whereas the term non-rotation indicates the anatomic situation in which the Treitz and the small bowel are right-sided and the entire colon is left-sided[3]. Such is usually an asymptomatic condition which can be occasionally encountered in adult patients[4].

While both the imaging features of intestinal malrotation in adults[5] as well as the diagnostic yield of multidetector computed tomography (MDCT) in the acute setting of large bowel obstruction have long been recognized[6], the added value of coronal reformatted or reconstructed images in the setting of colonic volvulus has only been recently reported[7].

Herein, we report a case of an acute colonic obstruction which was first thought to be due to an internal hernia of the transverse colon into the lesser sac at the plain abdominal film series, later shown by MDCT to be due to a colonic volvulus possibly resulting from a retrogastric dislocation of the splenic flexure and finally found at surgery to be a volvulus of the ascending colon in a non rotated midgut.

To the best of our knowledge, such a case has never been reported in the radiological literature.

CASE REPORT

A 54-year-old woman was referred to our institution to undergo an abdominal plain film series for acute onset of crampy abdominal pain, which was only partially relieved by antispastic drugs prescription in the 3 d before hospital admission.

The patient's past medical history was unremarkable as well as most of lab tests except for mild leukocytosis [white blood cells = 12 × 10^3/mL 89% neutrophils] and increased levels of both creatine-kinase (220 U/L, n.v. 0-140) and lactate dehydrogenase (500 U/L, n.v. 227-450). She had no previous history of abdominal surgery.

Plain films were performed in both the upright (Figure 1A) and supine position (Figure 1B). The upright film showed a huge air-fluid level in the right flank consistent with obstruction of the ascending colon along with some small bowel air-fluid levels in the lower pelvis and in the mid abdomen (Figure 1A). The supine film showed an abnormally dilated ascending colon with mild distension of some ileal loops in the pelvis whereas both the descending colon and the sigma appeared gasless. Faecal impaction could also be seen at the level of the hepatic flexure along with the associated evidence of an ab-extrinsic printing on the gastric body (Figure 1B). Based on this latter finding, a presumed diagnosis of colonic obstruction due to an internal hernia of the transverse colon into the lesser sac was postulated.

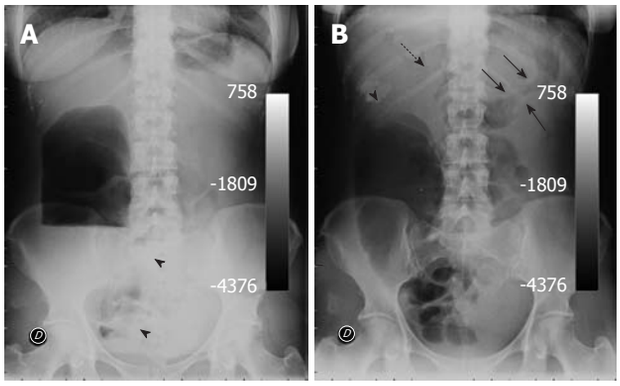

Figure 1 Abdominal plain films obtained in the upright (A) and supine position (B). A: A huge air-fluid level is depicted in the right flank consistent with the obstruction of the ascending colon. Some air-fluid levels can also be appreciated in the middle abdomen and in the right iliac fossa (arrowheads) whereas both the left flank and ipsilateral iliac fossa appeared gasless; B: The ascending colon appears abnormally dilated and there seems to be fecal impaction in the sub-hepatic space (arrowhead). Ab-extrinsic printing is also evident on both sides of the gastric body (arrows). Retrospectively, air bubbles can also be appreciated at the level of the hepatic hilum (dash arrow).

The patient was then submitted to a contrast-enhanced multi-detector abdominal CT (Aquilion 4, Toshiba, Japan) which was performed with a detector configuration of 3 mm × 4 mm, table feed of 9 mm/s, rotation time 0.5 s, beam pitch 1.5, 1.5 mm reconstruction intervals, section thickness of 3 mm, 300 mAs, 120 kVp. A monophasic acquisition was performed 70 s after *i.v.* bolus (2 cc/s) injection of 150 cc of iodinated non ionic contrast media (Ultravist 370, Bayer Shering Pharma, Berlin, Germany).

At MDCT, initial evaluation of axial images supported the diagnosis of internal hernia since a gas-containing loop was depicted within the hepatic hilum suggesting a herniation of the transverse colon through the foramen of Winslow (Figure 2A). However, colonic segments proximal to the splenic flexure also appeared distended by fluid and colonic distension could be traced back to the left iliac fossa where torsion of the mesenteric vascular axis (whirl sign) was clearly depicted suggesting a volvulus (Figure 2B). Coronal reformatted images were then obtained (Figure 3).

On the coronal oblique plane, colonic segments distal to the transition zone appeared distended by fluid throughout the splenic flexure whereas the descending colon was collapsed (Figure 3A). On the coronal plane (Figure 3B) the cecum appeared tilted and displaced in the sub-hepatic space.

The patient underwent immediate surgery. At laparotomy, a volvulus of the ascending colon was found and a right hemi-colectomy had to be performed because of ischemia of the involved segments. However, a concomitant malrotation was also found with the ligament of Treitz located in the right upper quadrant (Type 1) and the transverse colon displaced under the root of the mesentery. A derotation had to be performed. The patient had an uneventful recovery and was discharged 13 d later.

CT scans were then reviewed and a number of CT signs of malrotation were retrospectively found (Figure 4).

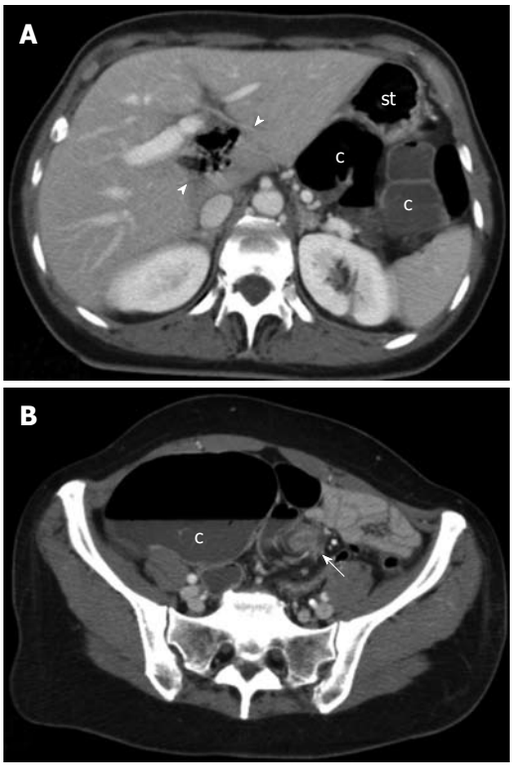

Figure 2 Multi-detector contrast-enhanced computed tomography. Transverse images at the level of the upper abdomen (A) and the pelvis (B) are shown. A: A gas-containing loop is clearly depicted within the hepatic hilum (arrowheads) along with the evidence of a colonic segment (c) situated behind the stomach (st); B: An abnormally dilated colonic segment misinterpreted on the axial plane as cecum (c) can be appreciated in the right iliac fossa whereas torsion of the mesenteric vascular axis (whirl sign) is clearly depicted in the left iliac fossa (arrow).

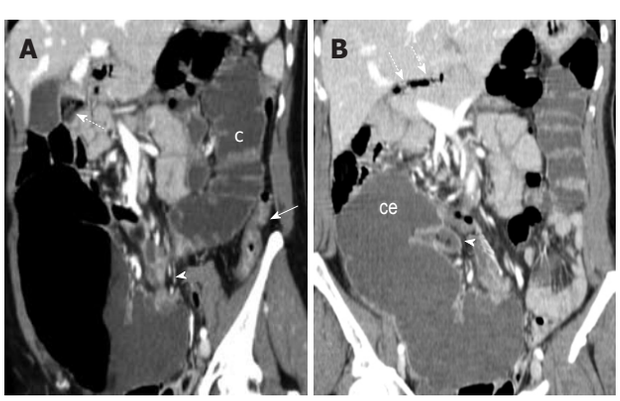

Figure 3 Multi-detector contrast-enhanced computed tomography. Reformatted images on an oblique coronal (A) and on the coronal plane (B) are shown. In A, colonic segments (c) distal to the transition zone (arrowhead) also appeared distended by fluid throughout the splenic flexure with a collapsed descending colon (arrow). Signs of fecal reflux can be appreciated besides the gall-bladder (dash arrow) accounting for the mottled appearance depicted in the sub-hepatic space on the plain film series (B). On the coronal plane (B), the cecum (ce) appears tilted in the sub-hepatic space as it can be appreciated by the location of the terminal ileum (arrowhead) which also exhibits signs of fecal reflux, dash arrows indicate gas bubbles at the level of the hepatic hilum.

DISCUSSION

Intestinal malrotation is a congenital anomaly resulting in an abnormal position of the small and/or the large bowel within the peritoneal cavity[2]. It includes a broad spectrum of fixation anomalies occurring when the midgut fails to complete the required 270° counterclockwise rotation during embryologic development. In particular, the term non-rotation indicates the anatomic situation in which the Treitz and the small bowel are right-sided and the entire colon is left-sided[3]. While this is usually an asymptomatic condition[4], it can rarely lead to an acute colonic obstruction due to volvulus of the ascending colon[8].

In our patient, the acute colonic obstruction was initially thought to be due to an internal hernia through the foramen of Winslow. These account for almost 8% of internal hernias defined as protrusion of an abdominal

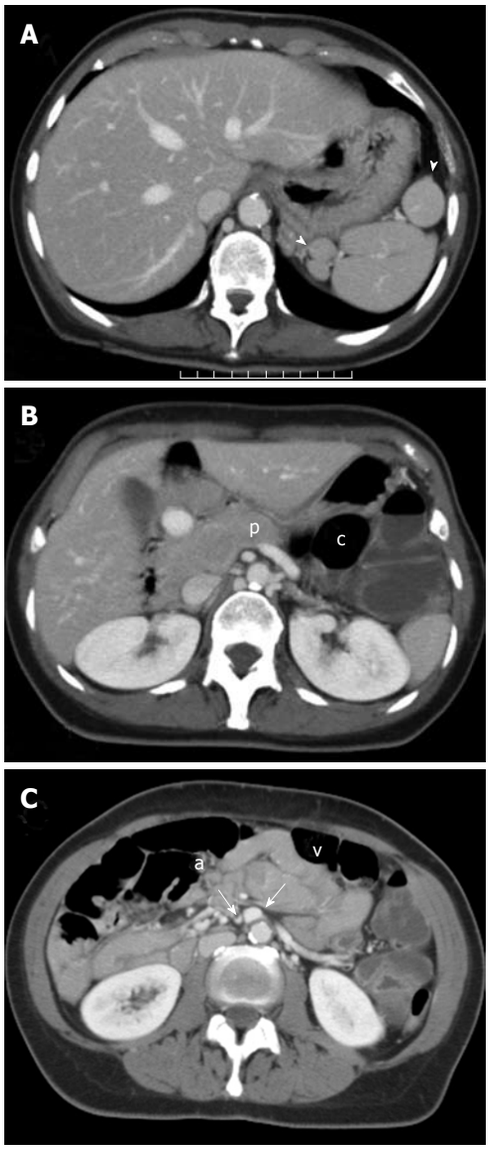

Figure 4 Multi-detector contrast-enhanced computed tomography. Transverse images at the level of the upper (A and B) and the middle abdomen (C) are shown. Retrospective reading of computed tomography images revealed multiple splenic nodules (poly-splenia) in the left sub-phrenic space (A) as well as a truncated appearance of the pancreatic body (p) (B) and an inverted anatomic relationship between the mesenteric superior artery (a) and vein (v) (C). c: Colon.

viscus through a natural or a pathologic defect in the peritoneal surface which can either be congenital or acquired following a trauma or a surgical procedure[9].

Almost one third of internal hernias through the foramen of Winslow may involve the large bowel, namely the transverse colon[10]. This was thought to be the case with our patient as the upright film showed a huge isolated air-fluid level in the right flank (Figure 1A) along with a mottled appearance in the sub-hepatic space and an ab-extrinsic printing on the gastric body, the latter most evident in the supine film (Figure1B).

This diagnostic impression was also confirmed by initial evaluation of transverse CT images which revealed intra-luminal gas bubbles at the level of hepatic hilum (Figure 2A). This finding was erroneously thought to be consistent with the diagnosis of internal hernia into the lesser sac. Conversely, CT findings of internal hernias through the foramen of Winslow should include the presence of mesenteric fat in the porto-caval space as well as the evidence of an air-fluid collection in the lesser sac with a beak directed toward the foramen of Winslow[9-11]. In our case, there only was a colonic segment situated behind the stomach (Figure 2A) without definite evidence of herniation.

Ours has, thus, to be considered an interpretative error. Retrospectively, gas bubbles at the level of the hepatic hilum (Figure 2A) could then be traced to either the duodenum, which was found at surgery to be confined to the right between the inferior vena cava and main portal vein and/or the Treitz which was found to be right-sided. Retrospectively, these air bubbles could also be appreciated in the supine film (Figure 1B) whereas the mottled appearance depicted in the sub-hepatic space could be traced to fecal reflux in the distal ileum as shown by the oblique coronal reformatted image (Figure 3A).

The ab-extrinsic printing on the gastric body (Figure 1B) was instead due to the retrogastric dislocation of the colon proximal to the splenic flexure as shown by CT (Figure 2A). As this usually represents a normal anatomic variation occasionally encountered in adults[12], in our patient it possibly represented the cause of the volvulus of the ascending colon which was found at surgery not be attached to the posterior peritoneum because of a congenital non rotation of the midgut. This latter was overlooked in the pre-operative CT but a number of CT findings suggestive of intestinal malrotation could be retrospectively appreciated (Figure 4).

First, a number of nodules isodense to the splenic parenchyma could be found in the left sub-phrenic space (Figure 4A) configuring a poly-splenia syndrome which is a condition correlated with intestinal malrotation either alone[13] or in association with agenesis of the dorsal pancreas[14] which it could also be retrospectively detected in our patient (Figure 4B). Finally, an inverted anatomic relationship of the superior mesenteric artery and vein was noted (Figure 4C). This represents the most accurate finding in intestinal malrotation which was first described in 1983[15].

However, CT clearly depicted the torsion of mesenteric vessels (whirl sign) suggesting the correct diagnosis of volvulus which was confirmed at surgery (Figure 2B). This finding is considered to have a high positive predictive value for the CT diagnosis of volvulus, for both small and large bowel[16]. It represents the twisting and engorgement of the mesenteric vessels around a central point in the peritoneal cavity and it is best appreciated when imaging is perpendicular to the axis of bowel rotation, hence the benefit of multiplanar reformations[6].

We have described a case of a surgically proven volvulus of the ascending colon in a patient with a non rotated midgut and a retrogastric dislocation of the colon proximal to the splenic flexure. To the best of our knowledge, such a case has not been previously reported.

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2012 35th Annual Meeting
Miami, FL 33169, United States

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Rome, Italy

February 13-16, 2012
Emergency Radiology
Palm Beach, FL 33480, United States

February 16-19, 2012
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Aalst, Belgium

April 25-28, 2012
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6 21st century heart solution may have a sting in the tail. *BMJ* 2002; **325**: 184 [PMID: 12142303 DOI:10.1136/bmj.325.7357.184]

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10 **Sherlock S**, Dooley J. Diseases of the liver and billiary system. 9th ed. Oxford: Blackwell Sci Pub, 1993: 258-296

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15 Morse SS. Factors in the emergence of infectious diseases. Emerg Infect Dis serial online, 1995-01-03, cited 1996-06-05; 1(1): 24 screens. Available from: URL: http://www.cdc.gov/ncidod/eid/index.htm

Patent (list all authors)

16 **Pagedas AC**, inventor; Ancel Surgical R&D Inc., assignee. Flexible endoscopic grasping and cutting device and positioning tool assembly. United States patent US 20020103498. 2002 Aug 1

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